BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Mission Analysis for the Third Manned Lunar Mission

TM- 69-2011-1

DATE- February 7, 1969

FILING CASE NO(S)- 310

AUTHOR(S)- T. L. Yang

FILING SUBJECT(S)- Lunar Exploration Mission
(ASSIGNED BY AUTHOR(S)- Mission Analysis

[redacted]
(ACCESSION NUMBER) (THRU)
51 NONE
(PAGES) (CODE)
CR-104032
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
[redacted]
FF No. 602(A)

AB:

Manned landing missions to seven lunar exploration sites have been studied for fiscal 1971. The results show that landing missions can be achieved with free return trajectories to the five sites located in the Apollo zone, while non-free return translunar trajectories are necessary to the two sites outside the Apollo zone. At least one launch opportunity exists per month per site. Most of the missions can be achieved with 2000 to 5000 lbs of excess CSM fuel remaining. By using both free return and non-free return trajectories, the monthly launch window can be extended to nine days for multiple landing sites and 48 hrs for a single site. Many problems concerning the fuel expenditure of the launch vehicle and the SPS can be solved through the use of non-free return trajectories; however, the landed payload is still limited by the LM propulsion systems.

Other topics studied include the effects of lighting constraints at lunar landing, the range of available approach azimuths for the lunar parking orbit, the effect of early or late LM lift-off, varying the number of revolutions in lunar parking orbit, and varying the translunar flight times. It is shown that substantial variations of these parameters are available within the total spacecraft ΔV capability.

In this study, patched conic trajectories are used to determine the ΔV costs and other mission dependent variables for each individual mission. The spacecraft weights and mission constraints used in this study are generally in agreement with those of the Apollo lunar landing missions.

(NASA-CR-104032) MISSION ANALYSIS FOR THE THIRD MANNED LUNAR MISSION (Bellcomm, Inc.) 51 p

N79-71605

Unclas
00/12 11477

BA-145A (8-68)

SEE REVERSE SIDE FOR DISTRIBUTION LIST

BELLCOMM, INC.

TM-69-2011-1

DISTRIBUTION

COMPLETE MEMORANDUM TO

CORRESPONDENCE FILES:

OFFICIAL FILE COPY
plus one white copy for each additional case referenced

TECHNICAL LIBRARY (4)

NASA Headquarters

R. J. Allenby/MAL
R. O. Aller/MAO
D. A. Beattie/MAL
G. H. Hage/MA
J. K. Holcomb/MAO
T. A. Keegan/MA-2
W. T. O'Bryant/MAL
S. C. Phillips/MA
L. R. Scherer/MAL
W. E. Stoney, Jr./MA
D. Wise/MAL

MSC

H. D. Beck/FM5
R. L. Berry/FM5
J. R. Elk/FM5
D. E. Fielder/FA4
J. R. Gurley/FM13
J. P. Loftus/HA
A. J. Meyer, Jr./HA
C. H. Perrine, Jr./PD

Bellcomm

F. G. Allen
G. M. Anderson
D. R. Anselmo
R. A. Bass
A. P. Boysen, Jr.
J. O. Cappellari, Jr.
K. M. Carlson
D. A. Corey

COMPLETE MEMORANDUM TO (CONTD.)

D. A. De Graaf
D. G. Estberg
L. P. Gieseler
D. R. Hagner
P. L. Havenstein
W. G. Heffron
N. W. Hinners
T. B. Hoekstra
B. T. Howard
D. B. James
S. L. Levie, Jr.
H. S. London
J. L. Marshall
J. Z. Menard
A. C. Merritt
G. J. Miel
V. S. Mummert
B. G. Niedfeldt
P. E. Reynolds
F. N. Schmidt
R. V. Sperry
J. W. Timko
R. A. Troester
R. L. Wagner
Department 1024 File

COVER SHEET ONLY TO

D. A. Chisholm
I. M. Ross

BA-145 (8-64)

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Mission Analysis for the Third Manned Lunar Mission
Case 310

DATE: February 7, 1969

FROM: T. L. Yang

TM-69-2011-1

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

Sites selected for future lunar exploration missions differ from the Apollo lunar landing sites in terms of location, terrain characteristics and mission objectives. A detailed study of the group of sites selected for the third lunar landing mission is presented in this memorandum. Topics to be discussed include the accessibility of these sites during specific time periods, the launch opportunities that can satisfy the given constraints, the admissible trajectory profiles and their corresponding ΔV requirements, the comparison of free return and non-free return trajectories and the penalties caused by increased spacecraft weights and extended stay time.

The study covers the one year period starting in July 1970. It is assumed that the current Apollo type vehicles will be used. Other mission constraints are identical to those to be used on the first two landing missions except that non-free return translunar trajectories are considered for those sites which are difficult or impossible to reach with free-return trajectories. The overall objective of the study is to find out if, and how, one can achieve landing missions to these seven sites with Apollo spacecraft and Apollo techniques, and, if some variations are necessary, to determine the corresponding tradeoffs in ΔV and payload. Some general information is available in the literature from earlier preliminary studies of the problem [1, 2, 3]. This study is intended to be more specific on sites and times and to provide more accurate quantitative information based on the latest available mission data.

The study was performed using patched-conic approximations. Small deviations from the results are to be expected when they are compared with precision integrated simulations.

2.0 METHODS AND ASSUMPTIONS

2.1 Location of the Sites

Two groups of lunar landing sites have been selected by the Site Selection Subgroup of the Group for Lunar Exploration Planning.* The first group, consisting of seven sites, are candidate sites for the third manned lunar landing mission. Five of these are inside the Apollo zone of interest (within $\pm$ 5° in latitude and $\pm$ 45° in longitude). The second group, selected for later extended LM three day missions, also consists of seven sites, all of which are outside the Apollo zone. These fourteen sites were selected primarily on the basis of scientific interest rather than accessibility. The location and terrain characteristics of some of these sites are quite different from those of the sites selected for the first two landing missions. The objectives of the third and the subsequent missions also differ from the first two missions.

The selenographic latitude and longitude of the seven landing sites selected for the third mission are listed below; their locations are shown in Figure 1.

i) II-P-2, 2°43.5'N, 34°24'E

ii) II-P-8, 0°29'N, 1°17'W

iii) III-P-12, 2°37'S, 42°32'W

iv) Fra Mauro, 3°45'S, 17°36'W

v) Abulfeda, 14°57'S, 14°18'E

vi) Littrow Rille, 21°44'N, 29°02'E

vii) Censorinus, 0°23'S, 32°32'E

Abulfeda and Littrow are the two sites located outside the Apollo zone.

2.2 Trajectory Generation and Payload Optimization

Trajectories to each of the sites were generated for each month using the mission analysis mode of the Bellcomm Apollo Simulation Program (BCMASP). The program uses patched-conic targeting techniques and calculates the delta velocity (ΔV) required at maneuver points by assuming impulsive burns. The corresponding fuel expenditure for each burn is computed

---

*Some changes have been made in more recent meetings. Please see "GLEP Site Selection Subgroup Third Meeting" by F. El-Baz, Bellcomm Memorandum for File B68 12106, December 19, 1968.

from the simple rocket equation. For free-return trajectories, a three dimensional optimization is carried out in the analysis by varying the lunar parking orbit approach azimuth, the geocentric flight path azimuth at the moon's sphere of influence (MSI) exit on the free-return trajectory, and the earth landing point within a given area. The quantity optimized is the total fuel consumption of the service module. For non-free return trajectories, the second parameter does not appear in the problem. Therefore, a two dimensional optimization is carried out. The translunar flight time is an additional parameter that can be used to optimize payload. However, it was not treated as a variable in this study in order to avoid excessive computer time. A fixed flight time of 100 hours was used. This value was chosen because previous analysis [see Ref. 1] demonstrated that it is generally near the true optimum. For some particular cases, shorter flight times were used because of unfavorable earth-moon geometry. The transearth flight time is constrained to be less than 115 hrs to limit the total mission duration. The earth landing point for a nominal return flight (not for the free-return flight) is constrained to be between +35° and -35° in latitude and between -150° and -170° in longitude.

Both Atlantic and Pacific translunar injections (TLI) were considered. The one that gives a better performance in fuel will generally be used but results from both are presented.

2.3 Lunar Orbit Operations

The standard procedure assumed in this analysis for lunar orbit operations is as follows. At the end of the translunar trajectory, the Command-Service Module (CSM) deboosts into a 60 N.M. circular parking orbit. After four revolutions in lunar orbit the Lunar Module (LM) separates from the CSM and makes an in-plane descent to the surface. After 24 hrs. on the lunar surface, the LM lifts-off and performs ascent and rendezvous with the CSM. Generally, the LM ascent orbit and the CSM parking orbit are not coplanar, and the required plane change is performed by the CSM. A ΔV allowance is provided for the CSM to rescue the LM from a 50,000 ft. circular orbit in case the LM is unable to complete the entire ascent and rendezvous.

The current plan for the first landing mission incorporates more than four revolutions in lunar orbit before separation. Therefore, the effects of increasing the number of parking revolutions were studied. The effect of increasing the surface stay time was also studied for comparison.

2.4 Lunar Lighting Conditions and Earth Launch Opportunities

In this study, the sun elevation angle at the time of lunar landing was constrained to be between 5° and 15° over the eastern horizon.* This constraint limits the acceptable time of landing to a certain period per month for each site. The length of the period depends on the latitude of the site. The period is approximately 18 hours for an equatorial site and increases gradually with the latitude. For a latitude of 40 degrees, the period is about 24 hours, beyond which it increases more rapidly as the site approaches the poles. Figure 2 shows the sun elevation angle as a function of time after sunrise for various latitudes. For the seven sites under consideration, the acceptable landing period ranges between 18 hours and 20 hours per month.

If free-return translunar trajectories are used, the earth-moon geometry generally permits only one launch opportunity per day (or at most, two, if both types of injections are acceptable). Once the launch opportunity is chosen, the translunar flight time is also fixed by the geometry. The above facts predetermine the daily times of lunar landing and daily times of earth launch. Because of the periodicity of the earth's motion, the consecutive landing opportunities are spaced approximately 24 hours apart. In some months, the period of acceptable lighting (18 ∿ 20 hours in length) falls between two consecutive landing opportunities (spaced approximately 24 hours apart). This means that none of the predetermined launch opportunities in that month can provide a landing with an acceptable lighting condition. In such a case, one will select the launch opportunity that corresponds to an early arrival and increase the number of revolutions in lunar parking orbit until the sun elevation angle reaches 5 degrees. The required increase in the number of revolutions is normally less than three.

When non-free return trajectories are used, there usually exists a wide range of translunar flight times which give acceptable trajectories. The time of lunar landing can then be controlled by varying the flight time. This additional degree of freedom makes it possible to meet any prescribed lighting condition at lunar landing. A number of trajectories were generated to demonstrate this technique.

2.5 Spacecraft Weight

The spacecraft weight used in this study was taken from the CSM-106 and LM-5 weight and performance definitions given in Reference 5. The table below gives the weight breakdown.

---

*This differs from the current Apollo constraint of 6° to 20°, but is consistent with the present MSC consideration of 5° to 14° (1/31/69 MSC Mission Review).

Inert Weights (lbs)	
CM (with crew and RCS fuel)	13,000
Total LM (less crew)	32,650
SLA	3,900

Usable Propellant Quantities (full tank, lbs)	
SM RCS	1,300
LM RCS	570
SM SPS	39,740
LM Ascent	5,040
LM Descent	17,510
Total Injected Weight (lbs)	100,000*

In the total LM weight and the total injected weight, the LM ascent tank and the CSM SPS tank have been slightly off-loaded (170 lbs and 1090 lbs respectively) to meet the assumed launch vehicle 100,000* lbs limit.

2.6 Launch Vehicle Capability

The launch vehicle is assumed to have the capability of injecting a payload of 100,000 lbs onto a translunar trajectory with a total energy of -8.05×10^6 ft^2/sec^2 which corresponds to a total velocity of 35935 fps** at an altitude of 100 N.M. An additional ΔV of 39 m/sec (128 fps) is provided

---

*The total injected control weight has since been increased to 101,500 lbs.

**The more recent figure for launch vehicle capability, 101,500 lbs injected at 35,935 fps, is equivalent to approximately 100,000 lbs injected at 36,200 fps.

as "flight geometry reserve". However, not all of this reserve was considered as additional ΔV allowance since part of it will be needed for the dual TLI opportunity capability. The total plane change required for this capability is a mission dependent quantity ranging between 0.0 and 2.1 degrees for the first opportunity, and between 0 and 1.2 degrees for the second opportunity. Accordingly, an allowance for a 2.1° TLI plane change is assumed in the analysis. This amounts to an additional ΔV of 63 fps when the plane change is incorporated in the TLI burn (having a total ΔV of approximately 10,000 fps); therefore, 63 fps is taken from the reserve to provide for the dual TLI capability. The remaining 65 fps in the flight geometry reserve is added to the launch vehicle capability making a total possible injected velocity of 36,000 fps. A ΔV of 40 fps is subtracted from the capability in order to compensate for the conic approximations.

The earth parking orbit is assumed to be 100 N.M. circular and the launch azimuth is assumed to be 90 degrees. The resulting inclination of the parking orbit plane generally supplies two in-plane TLI opportunities (a Pacific injection and an Atlantic injection) in each day. Occasionally, the resulting parking orbit plane inclination provides no in-plane TLI opportunities because of large lunar declination. In such a case, BCMASP will make a minimum adjustment to the launch azimuth to provide an in-plane TLI.

2.7 CSM and LM ΔV Budgets

The ΔV budget for the CSM SPS is shown in Table 1, which is taken from Reference 5. A summary of the budget is given below.

	ΔV, fps
Translunar midcourse correction	130
Transearth midcourse correction	62
CM G&N failure and any orbit return capability	178
LM Rescue	790

Note that Table 1 only contains items that are mission independent. The ΔV required for lunar orbit insertion (LOI), CSM plane change before rendezvous (CSMPC), and transearth injection (TEI) are the variables to be studied for each individual mission.

In this study, the LM is given the least fuel demanding type of operation -- an in-plane descent from a 60 N.M. parking orbit and an in-plane ascent from the landing site. It is therefore assumed that the required LM ΔV is within its budget and it becomes mission independent.

The fuel cost for the CSM to deliver the LM to a 50,000 ft circular orbit and to return to a 60 N.M. parking orbit was studied for certain typical missions. An additional ΔV of 290 fps is needed for these maneuvers.

3.0 RESULTS

3.1 General Accessibility

The study of individual missions showed that with the current Apollo capability and constraints (except free return), it is possible to achieve lunar landing missions to any of the seven sites once every month throughout fiscal 1971. Earlier studies on accessibility [6, 7] showed that all of the seven sites except Abulfeda and Littrow Rille are within the region that is always accessible with free-return translunar trajectories during the considered time period. Abulfeda is located in the "some days accessible" region and Littrow Rille is not accessible with free-return trajectories. It was also shown that all seven sites are located in the "always accessible region" when non-free return trajectories are used. Although the spacecraft weights, ΔV budgets, and some mission constraints have been changed since these earlier studies were made, the results of this study on the seven sites are in agreement with the earlier findings. Non-free return trajectories must be used in all of the twelve months for Littrow Rille and in nine of the twelve months for Abulfeda. The remaining five sites are always accessible with free-return trajectories.*

3.2 ΔV Requirements and Spacecraft Performance

The ΔV required for TLI, LOI, CSMPC (CSM plane change) and TEI are mission dependent and are determined explicitly for each individual mission. The results are discussed separately below. Details of these results are presented in the attached

*In September of 1970, the CSM fuel costs for free return trajectories to III-P-12 and Fra Mauro were within 500 lbs of the limit. For such marginal cases the results should be verified by integrated trajectories to eliminate errors caused by the conic approximations.

figures. The type of translunar injection is indicated in these figures by the letters A for Atlantic injection and P for Pacific injection. Points corresponding to the type of injection resulting in a better CSM fuel performance are connected by line segments. It should be noted that only one trajectory was generated in each monthly launch window; therefore, the line segments do not represent interpolated data for days between launches.

The required TLI total velocities are shown in Figures 3 to 9. Among all the missions considered, none of the required TLI velocities exceeded the specified capability of 36,000 fps. However, if the 40 fps conic calibration is added to the required velocity, a few cases in 1971 exceeded the capability.* All except one of these cases can be taken care of by offloading some or all of the excess SPS fuel. A reduction of 10 lbs in total injected weight will increase the launch vehicle capability by approximately 1 fps. The exception is the free-return mission to Abulfeda in March, 1971. One may either make a precision integrated simulation to find the accurate fuel costs or use a non-free return trajectory for this month.

It is observed that the TLI velocity varies little with respect to the time of launch, the location of the site, or the type of injection. The value falls within 35950 ± 25 fps for free-return trajectories and within 35870 ± 25 fps for non-free return trajectories (for the selected flight time).

The ΔV's required for LOI, CSMPC and TEI are shown in Figures 10 to 16. These items are the mission dependent ΔV costs for the SPS. It is observed that the LOI ΔV cost is generally the dominating factor in the determination of the total fuel performance. Other than this, the behavior of these ΔV costs is seen to be quite mission dependent. Since the costs for both type of injections are shown, the figures provide an interesting itemized ΔV cost comparison between the two types of injection.

Some sudden jumps are found in the TEI ΔV cost. These are caused by the restriction of the maximum allowable transearth flight time of 115 hrs. Taking site II-P-2 as an

---

*All would be within the capability if the more recent limit of 36,200 fps were used.

example, the translunar flight times for September and November of 1970 are 110 and 113 hrs respectively. The flight time for the December mission would be 116 hrs if no restriction were imposed. Since 116 hrs exceeds the 115 hrs limit and since the earth landing area is constrained, BCMASP selects the next lower usable flight time which is about 24 hours shorter. The resulting transearth flight time of 92 hrs requires a much higher TEI velocity thus causing the jump in Figure 10.

Since the same total injected weight is used for all missions being studied, the overall performance for each mission can be studied in terms of the excess usable fuel weight remaining in the service module after making the transearth midcourse corrections. The results are shown in Figures 17 to 23. The excess fuel weight for missions to the five free-return sites ranges between 2000 lbs and 3000 lbs. However, there are a few months in 1970 when the excess weight for missions to III-P-12 and Fra Mauro becomes lower. The excess SPS fuel weight for the two non-free return sites is considerably higher, ranging between 4000 and 5000 lbs.

Suppose that the amount of excess SPS fuel is off-loaded before launch and an equal amount of weight is added to the LM. Then the SPS fuel requirement will remain unchanged up through LOI. The fuel requirement for the transearth phase will be decreased because there is no excess fuel to be carried through the maneuvers. Consequently, the additional payload capability into lunar orbit is actually more than the excess fuel weight shown in these figures. Additional studies showed that 1000 lbs of excess SPS fuel can be traded for approximately 1500 lbs of payload into a 60 N.M. parking orbit.

Because of the limited LM fuel capability, only a fraction of the additional payload may be delivered to the lunar surface. However, part of the excess fuel may be used by the CSM to deliver the LM into a lower circular orbit. This would enable the LM to land more weight with the same propulsion system. An additional ΔV of 290 fps is required for the CSM to deliver the LM from a 60 N.M. circular orbit into a coplanar 50,000 ft circular orbit and return. This maneuver would reduce the LM ΔV budget by 145 fps (72 fps for eliminating the DOI maneuver and 73 fps for circularization at 50,000 ft). The corresponding fuel weights for these maneuvers are mission dependent since they involve the CSM weight. In a number of sample missions (using the same total injected weight of 100,000 lbs and a standard LM weight of 32,650 lbs) the SPS fuel cost for delivering the LM to a 50,000 ft circular orbit varied between 980 lbs and 1100 lbs. The corresponding LM fuel weight saved is on the order of four hundred pounds for a standard LM. This weight amounts to a true increment in surface payload.

3.3 Lunar Approach Azimuth

The BCMASP program selects an approach azimuth by scanning over a specified range of angles at two degree intervals. The angle which results in the best performance in total fuel consumption is chosen for the mission. The azimuth so chosen may sometimes be unsuitable for reasons such as undesirable characteristics of the approach terrain. In such a case, a different approach azimuth would be used with some penalty in fuel expenditure. Figures 24 to 30 show the monthly variation of the optimum approach azimuth and the range of available azimuths within the CSM capability. It can be seen that the optimum azimuth for a given site varies gradually from month to month and the available range of azimuth forms a band about the optimum ones. The band stays wider than 20 degrees with only a few exceptions. In some cases, the BCMASP program did not scan the entire range of acceptable azimuths. The ranges for these cases are found by extrapolation. Values found by extrapolation are indicated by dashed lines in the figures.

3.4 Abort Before Nominal Lift-Off

An opportunity for an early LM lift-off exists each time the CSM flies over the landing site. The period of a 60 N.M. parking orbit is approximately 2 hrs. There are, therefore, a total of eleven early opportunities in a 24 hrs. stay time. Two major changes in the trajectory profile occur as consequences of an early lift-off: the amount of CSM plane change before rendezvous will differ from the nominal value, and TEI will occur in a different plane and probably at an earlier time. The effect of the first change can be deduced from Reference [8], in which the amount of CSM plane change is shown as a function of actual stay time, site latitude, and approach azimuth of the parking orbit. In the missions covered in this study, the required CSM plane change for an early lift-off turned out to be less than that of the nominal with only two exceptions. The exceptions are missions to Abulfeda and Littrow Rille when the approach azimuth was chosen to be 90 $\pm$ 2 degrees. In these cases, there may be a small plane change penalty for an early lift-off. The maximum of this penalty is approximately .5 degree, corresponding to a ΔV of 45 fps which causes no difficulty. The TEI maneuver following an early lift-off may be planned in either of two ways: at about the nominal time, or, as soon as possible. If, after rendezvous, the CSM stays in the LPO until the nominal TEI time the necessary change in the trajectory profile will be minimized. However, it is more likely that TEI would be performed as soon as possible. In this case the trajectory has to be changed because of the change in earth-moon geometry caused by the shift in TEI time. The effect of this change is similar to that of shortening or lengthening the stay time, in that it may either increase or decrease the required fuel. A more detailed discussion of the effects appear in the following section.

3.5 Variable Number of Lunar Revolutions and Extended Stay Time

A number of trajectories were generated to study the effect of increasing the number of revolutions before landing from three to ten and the effect of extending the stay time from 24 hours to 36 hours.* The results are summarized in Table 2. The two particular launch opportunities were selected because they represent the best and worst cases (in terms of fuel performance) in the 12 month period for the Fra Mauro site.

Each additional revolution before LM descent delays the time of landing by approximately two hours and increases the sun elevation angle by one degree. If the new sun elevation angle is still within the acceptable range, the same launch date can be used. Otherwise, the date of launch will be moved to one day earlier, as occurred in the first case in Table 2. In either case, there is little change in the translunar phase of the trajectory, but some changes are observed in the lunar landing phase and the transearth phase.

Extending the stay time has two major effects on the trajectory: it changes the amount of the CSMPC (CSM plane change) and delays the time of TEI. These changes may increase or decrease the required ΔV depending on the particular trajectory. If a stay time of longer than 24 hrs is used in mission planning, the change in ΔV costs will vary the optimum approach azimuth. Since the BCMASP program works with two degree steps in scanning the azimuth, a change of several hours in stay time generally does not cause enough variation to shift the optimum azimuth. Assuming that the same approach azimuth is used, the amount of change in CSMPC due to extending the stay time can be deduced from Reference [8]. For most of the missions covered in this study, the required plane change is increased by from .5 to 1.0 degree. During TEI, the CSM makes a plane change, from the LPO plane into the transearth trajectory plane, and simultaneously attains the required TEI ΔV. For a

---

*Twelve hrs is probably the longest extension one can consider without changing the LM configuration.

given time of TEI, the TEI ΔV must be selected to result in a trans-earth flight time which permits the splash-down to occur in the designated area. Therefore, the inertial position of this area at TEI and the earth-moon distance at TEI both affect the required ΔV. A change in the time of TEI results in a different angle between the LPO and the trajectory plane as well as a different earth moon geometry. The combined change in plane change and required ΔV may result in either an increase or a decrease in the fuel cost. In the two cases shown in Table 2, the maximum deviations caused by the increased number of revolutions combined with the extended stay time are 74 fps in CSMPC ΔV, 109 fps in TEI ΔV and 485 lbs in total fuel weight. These quantities give an example of the possible penalty due to these changes.

3.6 Launch Window and Translunar Flight Time

As mentioned before, the 5° to 15° sun elevation angle constraint limits the acceptable time of landing to about 20 hours per month for each site. If free-return trajectories are used, the translunar flight time becomes a function of the day of launch, staying almost constant over a period of a few days. One may select the appropriate number of lunar parking orbit revolutions and the type of translunar injection to develop two consecutive launch opportunities such that landing occurs at the beginning of the good lighting period for the first launch opportunity and at the end of the period for the second. The duration of the monthly launch window so achieved is approximately 24 hrs for a given site. If non-free return trajectories are also considered, the translunar flight time can be used as an additional parameter to shift the time of launch. A monthly launch window of 48 hours to the same site can be achieved without difficulty. Table 3 shows a sequence of missions demonstrating this technique. The times of the first launch and the last launch in Table 3 are separated by more than 48 hrs and yet landing occurs at nearly the same time (indicated by the sun elevation angles).

If free return trajectories are used and several sites are considered in one month, a monthly launch window of 7 days results. A difference of 12 degrees in landing site longitude corresponds to a difference of approximately 24 hours in earth launch time. For instance, the monthly opportunities to the following sites occur in the sequential order: II-P-2, II-P-8, Fra Mauro and III-P-12. If the launchs are scheduled accordingly, they will be separated by 72 hours, 48 hours, and 48 hours respectively. If non-free return trajectories are considered, the monthly launch window can be widened to nine days.

With non-free return translunar trajectories the flight time may be varied for the purpose of adjusting the lighting condition at lunar landing. Table 4 shows the results of a few sample missions. In these missions an increment of 5 hrs in flight time raises the sun elevation angle at landing by two to three degrees.

4.0 SUMMARY AND CONCLUSIONS

Manned missions during fiscal 1971 to seven landing sites selected for lunar exploration missions were studied in detail to determine the existence of launch opportunities, the trajectory profiles, the ΔV costs, the fuel performance, etc. The results of this study and the conclusions deduced from the results are summarized below.

i) Landing missions can be achieved to all seven sites. There exists at least one launch opportunity per month per site throughout fiscal 1971.

ii) Non-free return translunar trajectories are required to land at Littrow Rille for all 12 months, and for 9 of the 12 months to land at Abulfeda.

iii) The available range of the approach azimuth for the lunar parking orbit is generally wider than 20 degrees.

iv) The lighting constraint of 5° to 15° can always be satisfied. However, the number of revolutions in lunar parking orbit prior to LM descent must be increased in some cases in order to achieve this.

v) There is at most a very small penalty in CSM plane change for an early LM lift-off. After an early LM lift-off, TEI may also be performed early resulting in only a small change in TEI ΔV.

vi) Increasing the number of revolutions in lunar parking orbit (from 3 to 10) or extending the stay time (from 24 to 36 hrs) usually increases the amount of CSM plane change. It also delays the time of TEI resulting in a change in TEI fuel cost. However, the combined net change in fuel cost is found to be generally insignificant.

vii) Using a fixed total injected weight, the SPS excess fuel for these missions ranges between 2000 and 3000 lbs for free-return trajectories and between 4000 and 5000 lbs for non-free return trajectories. A portion of the excess SPS fuel weight may be transferred to landed payload by letting the CSM deliver the LM to a 50,000 ft circular orbit.

viii) The monthly launch window for landing at different sites is seven days wide when free return trajectories are used. It becomes nine days wide when both free and non-free return trajectories are used.

ix) The monthly launch window for landing at the same site can be extended to 48 hrs by using one free return trajectory and two non-free return trajectories with different translunar flight times.

As a whole, the removal of the free return constraint eases the fuel requirements on the launch vehicle and the SPS considerably. Other problems such as lighting constraints and the duration of the monthly launch window are also overcome by the use of non-free return trajectories. However, none of these contribute significantly to increasing the landed payload.

Ta-lun Yang

2011-TLY-vh T. L. Yang

Attachments
References
Tables 1 - 4
Figures 1 - 30

REFERENCES

1. D. R. Anselmo and W. D. Kinney, "Lunar AAP Mission Profiles", Bellcomm TM-67-2011-1, September 29, 1967.

2. G. R. Babb, Jr., "A Preliminary Study of a Lunar Landing Mission to Copernicus", MSC Internal Note No. 68-FM-39, February 14, 1968.

3. G. R. Babb, Jr., "A Preliminary Study of AAP Lunar Landing Missions", MSC Internal Note No. 67-FM-121, August 23, 1967.

4. F. Heap, "Lunar Lighting Meeting at MSC", Bellcomm Memorandum for File B68-0278, February 19, 1968.

5. G. M. Low, "Apollo Spacecraft Weight and Mission Performance Definition", MSC Publication, December 12, 1967.

6. J. O. Cappellari, Jr., W. D. Kinney, A. A. Satterlee, R. D. Tigner, "A Study of the Behavior of Lunar Accessibility Over Extended Time Periods, Part I - Free Return Trajectories", Bellcomm TR-65-209-4, May 25, 1965.

7. J. S. Dudek, W. D. Kinney, K. Smith, "A Study of the Behavior of Lunar Accessibility Over Extended Time Periods, Part II - Non-Free Return Trajectories", Bellcomm TR-65-310-1, October 22, 1965.

8. T. L. Yang, "Charts of Required Total Plane Change Prior to CSM and LM Rendezvous", Bellcomm Memorandum for File B68-09003, September 4, 1968.

	ΔV REQUIREMENTS, FPS	
	MISSION PHASES WITH LM	MISSION PHASES WITHOUT LM
NOMINAL MANEUVERS		
LUNAR ORBIT INSERTION	MISSION DEPENDENT	MISSION DEPENDENT
PLANE CHANGE IN LUNAR ORBIT	"	"
TRANSEARTH INJECTION	"	"
TRAJECTORY DISPERSIONS	120	62
CONTINGENCIES		
CM G&N FAILURE IN LUNAR ORBIT	0	128*
CAPABILITY TO RETURN FROM ANY LUNAR ORBIT	0	125*
LM RESCUE	0	790
INFLIGHT FLEXIBILITIES		
TWO TRANSLUNAR INJECTION OPPORTUNITIES	10	0
VARIATIONS IN LUNAR STAY TIME	0	MISSION DEPENDENT
TOTAL (MISSION INDEPENDENT REQUIREMENTS)	130	1030

*THESE REQUIREMENTS ARE RSS'D
SUM = 178 FPS

TABLE I - SPS DELTA V REQUIREMENTS

SITE : FRA MAURO (FREE RETURN)

EARTH LAUNCH		REV. IN LPO	STAY TIME HRS	SUN ELV. ANGLE AT TIME OF LANDING DEGREES	TLI VEL. FPS	TEI ΔV FPS	EXCESS CSM FUEL LBS
DATE	TIME						
9-7-1970	11:30	3	24	11.02	35,950	2,690	163
9-7-1970	11:30	3	36	11.02	35,950	2,799	-123
9-6-1970	11:10	10	24	6.25	35,953	2,771	-184
9-6-1970	11:10	10	36	6.25	35,953	2,798	-322
4-1-1971	22:10	3	24	7.03	35,968	2,598	2,886
4-1-1971	22:10	3	36	6.93	35,969	2,573	2,959
4-1-1971	22:10	10	24	14.00	35,969	2,550	2,967
4-1-1971	22:10	10	36	14.00	35,969	2,601	2,746

TABLE 2 - TYPICAL EFFECTS OF VARYING THE NUMBER OF REVOLUTIONS IN THE LPO AND EXTENDING THE STAY TIME

SITE : FRA MAURO

EARTH LAUNCH		FREE OR NON-FREE RETURN	TRANSLUNAR FLIGHT TIME HRS	SUN ELV. ANGLE AT LUNAR LANDING DEGREES	EXCESS CSM FUEL LBS
DATE	TIME				
MAR 31, 1971	05:50	N	120	12.11	3082
APR 1, 1971	05:45	N	95	11.36	2561
APR 2, 1971	05:40	F	71	10.80	1256

TABLE 3 - A TYPICAL MONTHLY LAUNCH WINDOW FOR LANDING MISSIONS TO A SINGLE SITE

SITE : FRA MAURO (NON-FREE RETURN TRAJECTORIES)

TRANSLUNAR FLIGHT TIME HRS	SUN ELV. ANGLE AT LUNAR LANDING DEGREES	EARTH LAUNCH	
		DATE	TIME
95	11.36	APR. 1, 1971	05:45
105	3.90	MAR. 31, 1971	04:50
110	6.67	MAR. 31, 1971	05:10
115	9.18	MAR. 31, 1971	05:30
120	12.11	MAR. 31, 1971	05:50

TABLE 4 - SUN ELEVATION ANGLE AT LANDING AS A FUNCTION OF TRANSLUNAR FLIGHT TIME

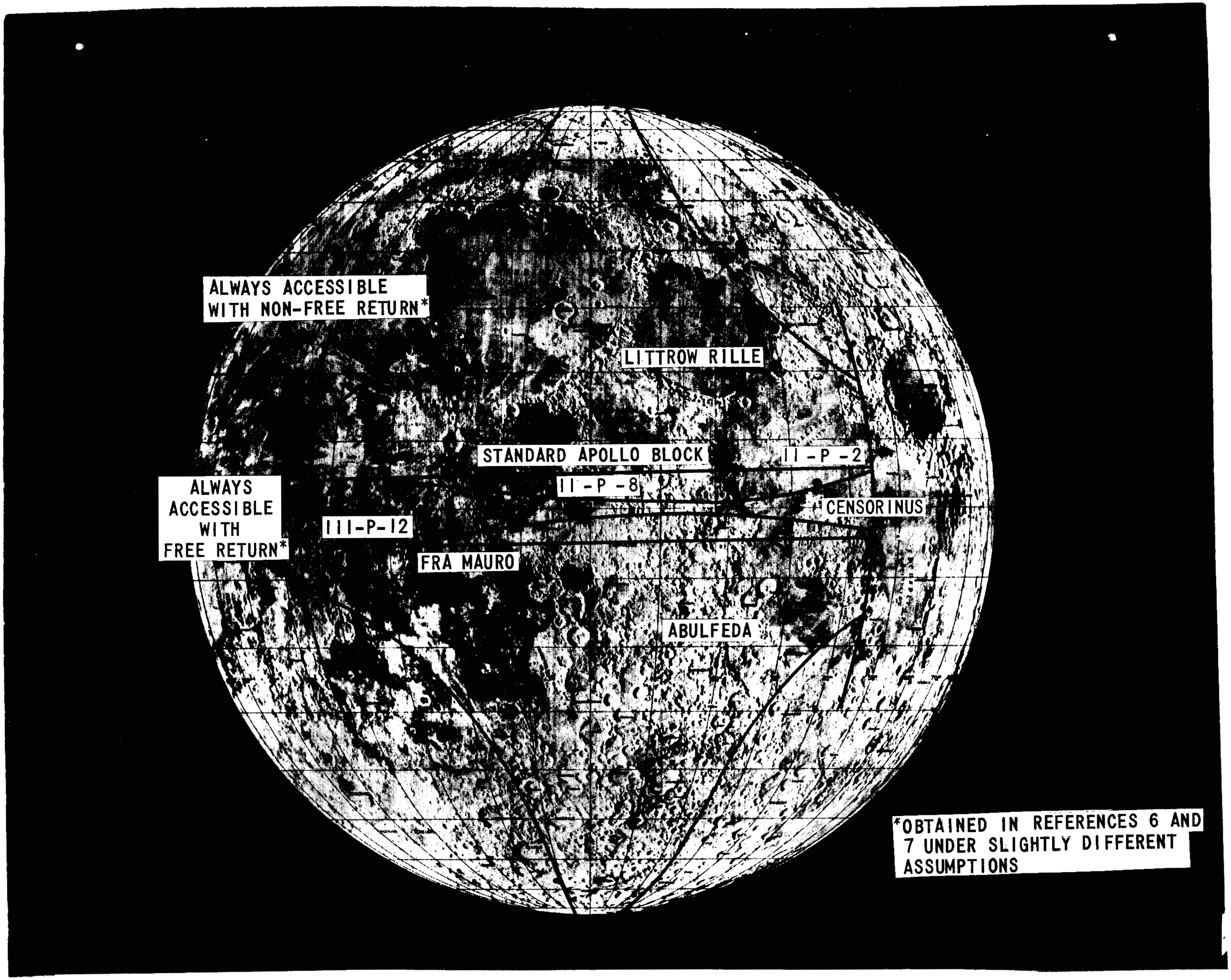

FIGURE 1 - LOCATION OF THE PROSPECTIVE THIRD MISSION SITES

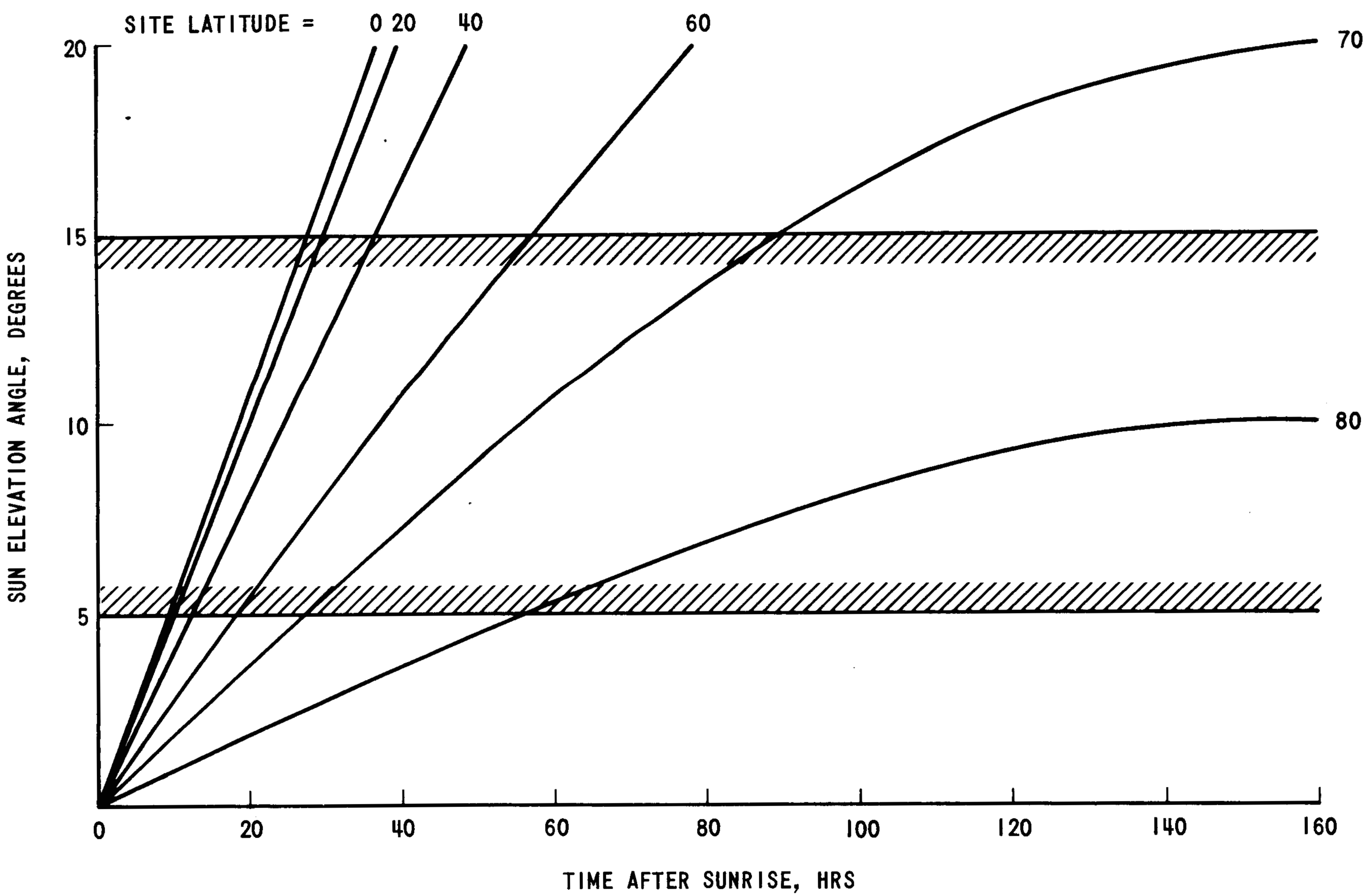

FIGURE 2 - LOCAL SUN ELEVATION ANGLE

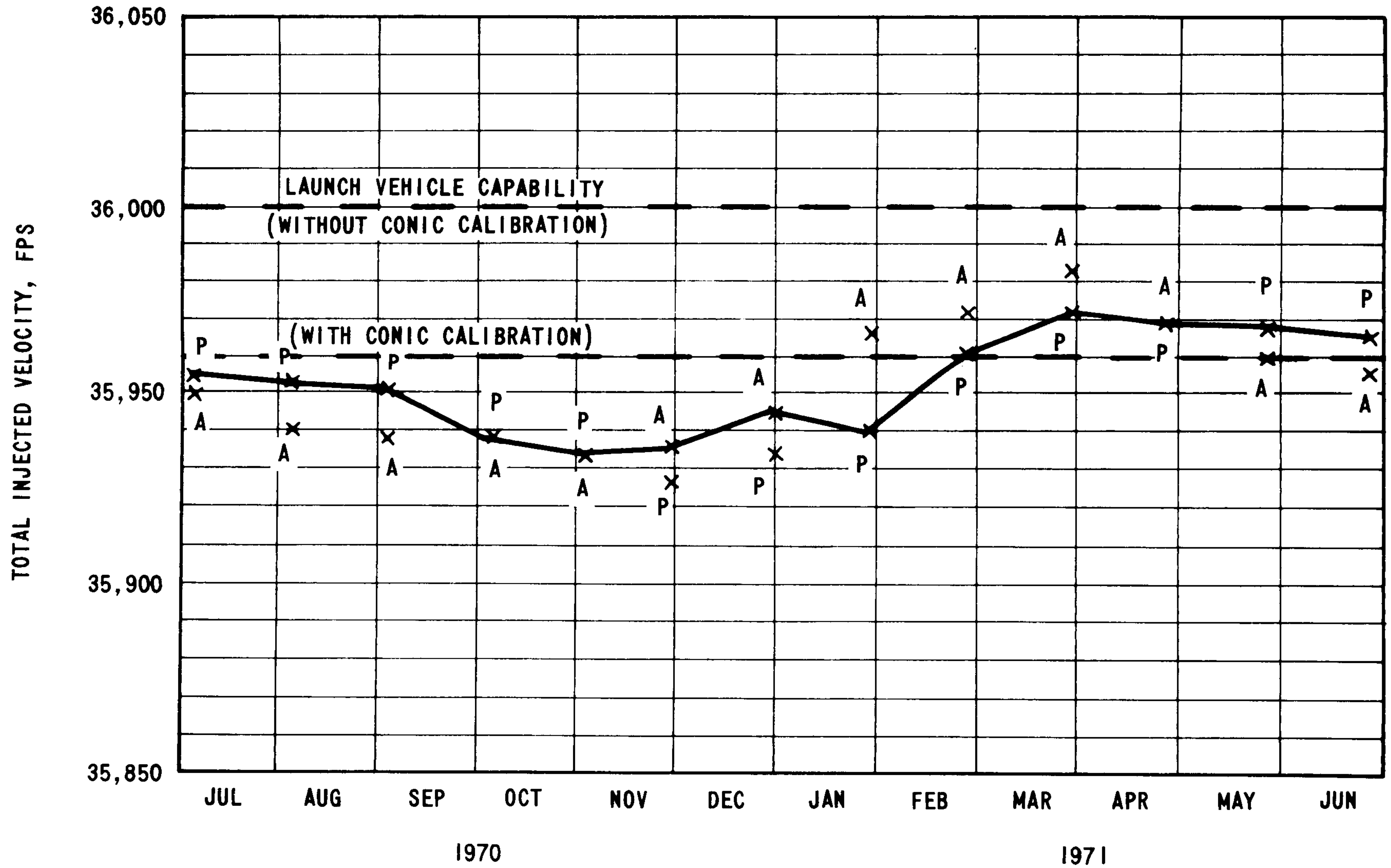

FIGURE 3 - TLI TOTAL VELOCITY FOR MISSIONS TO II-P-2
(FREE RETURN CONIC TRAJECTORIES)

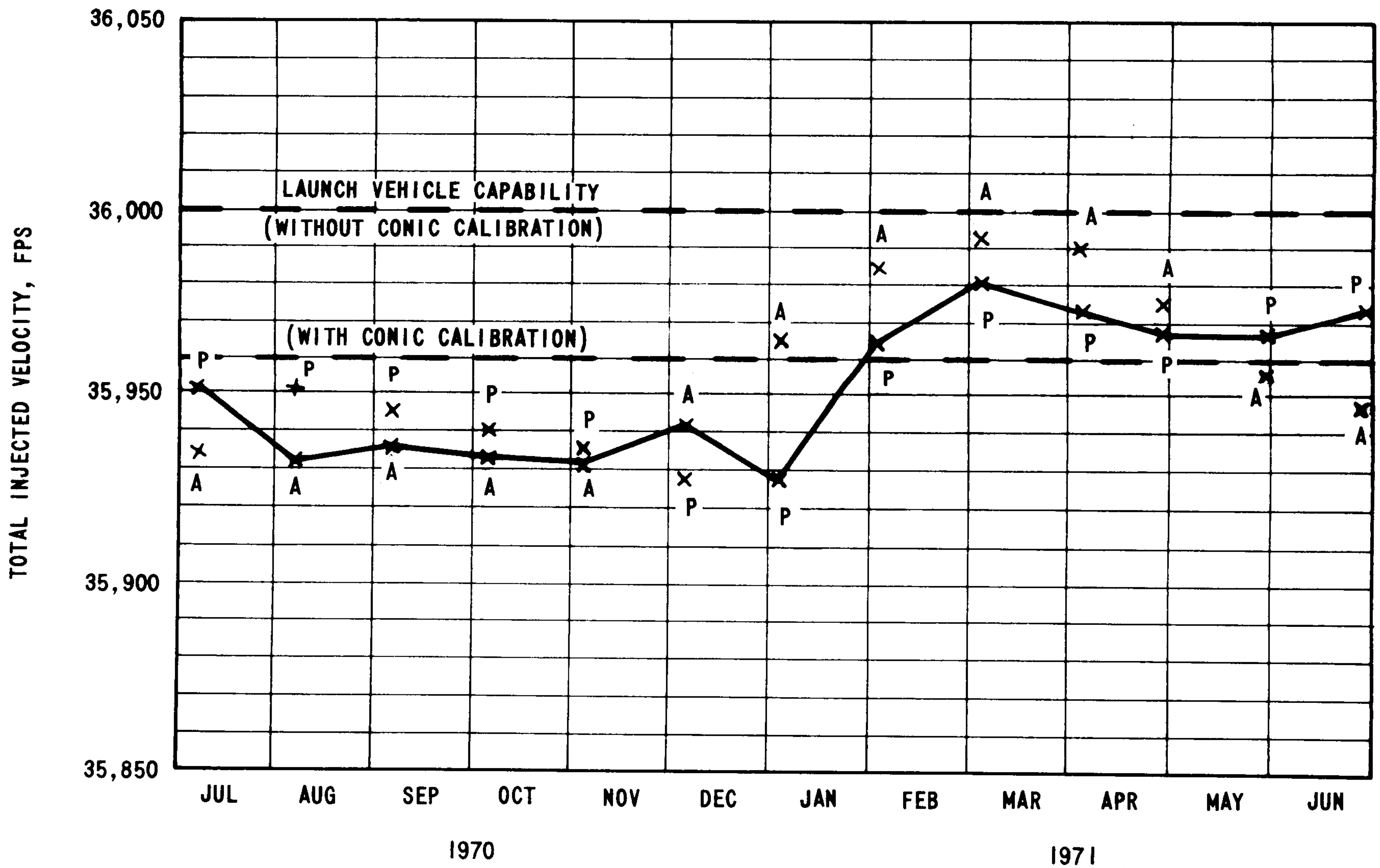

FIGURE 4 - TLI TOTAL VELOCITY FOR MISSIONS TO II-P-8
(FREE RETURN CONIC TRAJECTORIES)

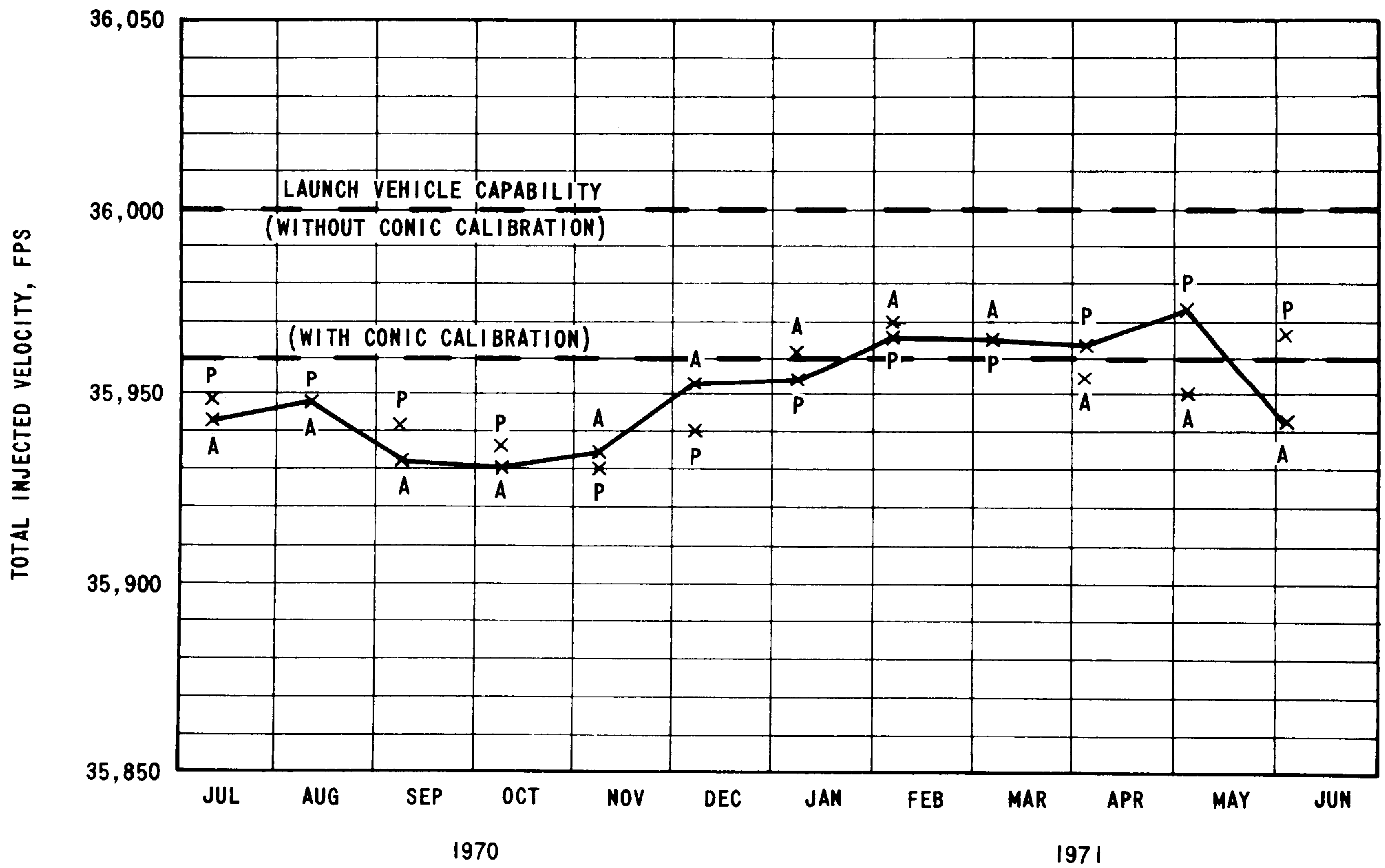

FIGURE 5 - TLI TOTAL VELOCITY FOR MISSIONS TO III-P-12
(FREE RETURN CONIC TRAJECTORIES)

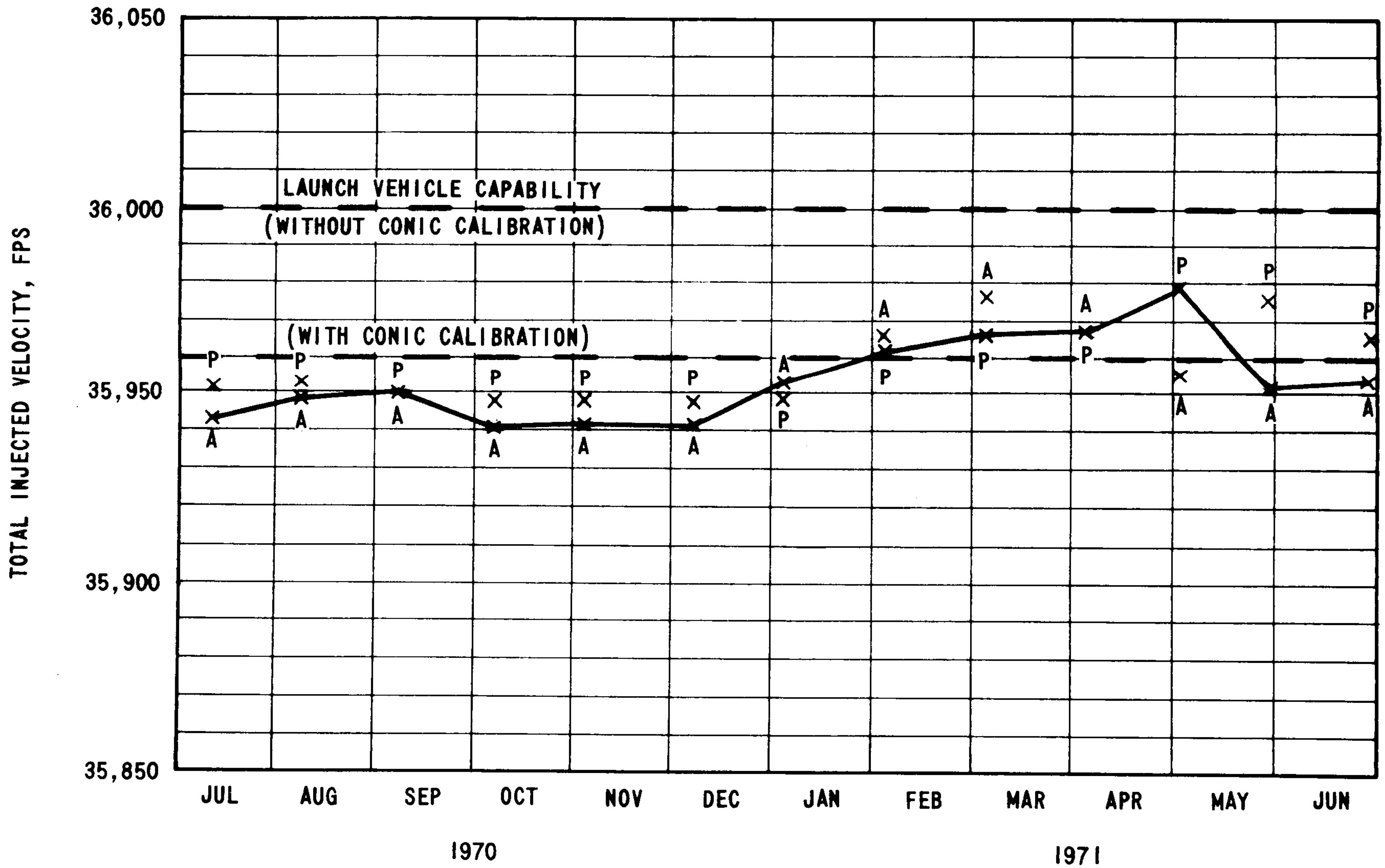

FIGURE 6 - TLI TOTAL VELOCITY FOR MISSIONS TO FRA MAURO
(FREE RETURN CONIC TRAJECTORIES)

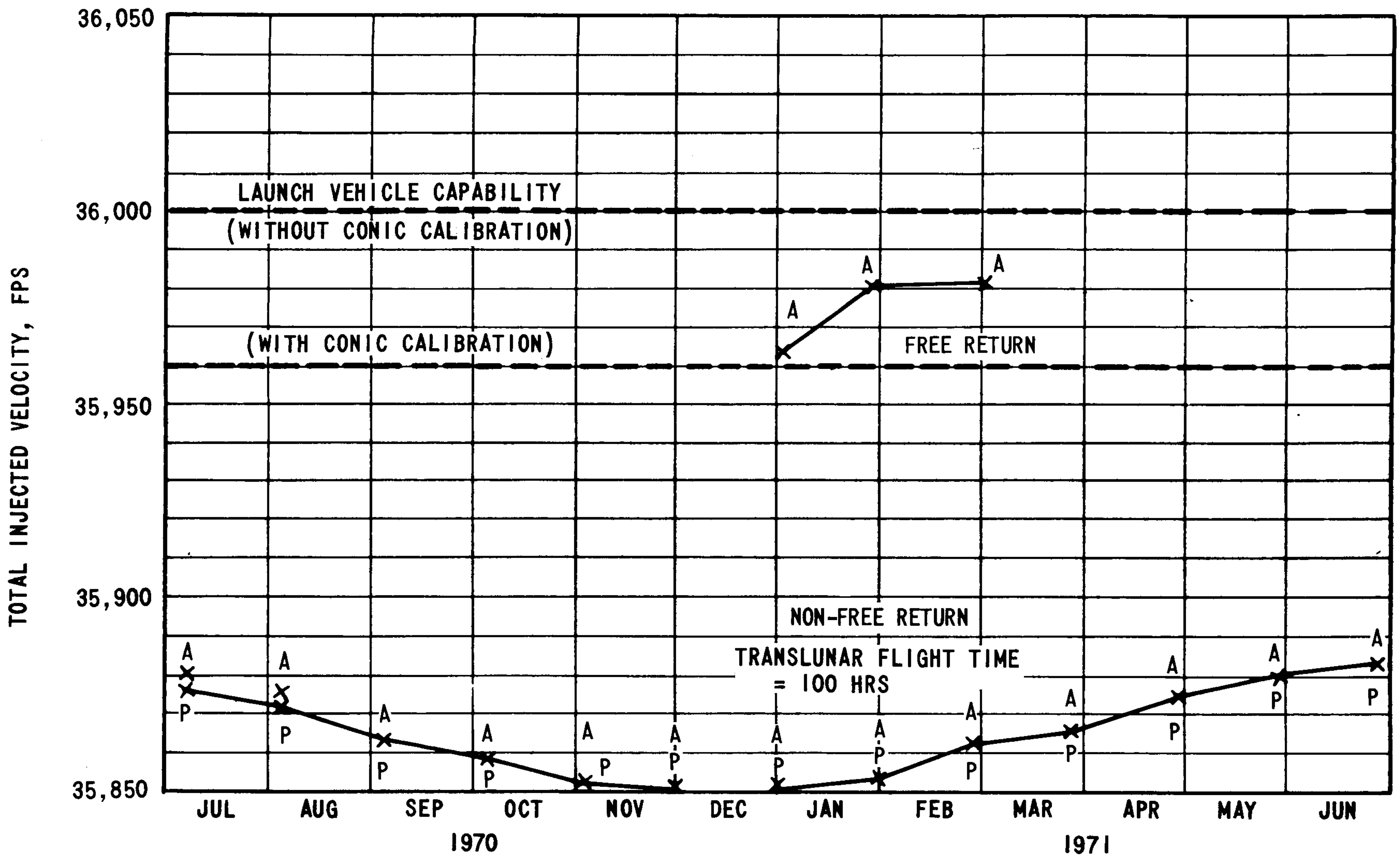

FIGURE 7 - TLI TOTAL VELOCITY FOR MISSIONS TO ABULFEDA
(FREE RETURN AND NON-FREE RETURN CONIC TRAJECTORIES)

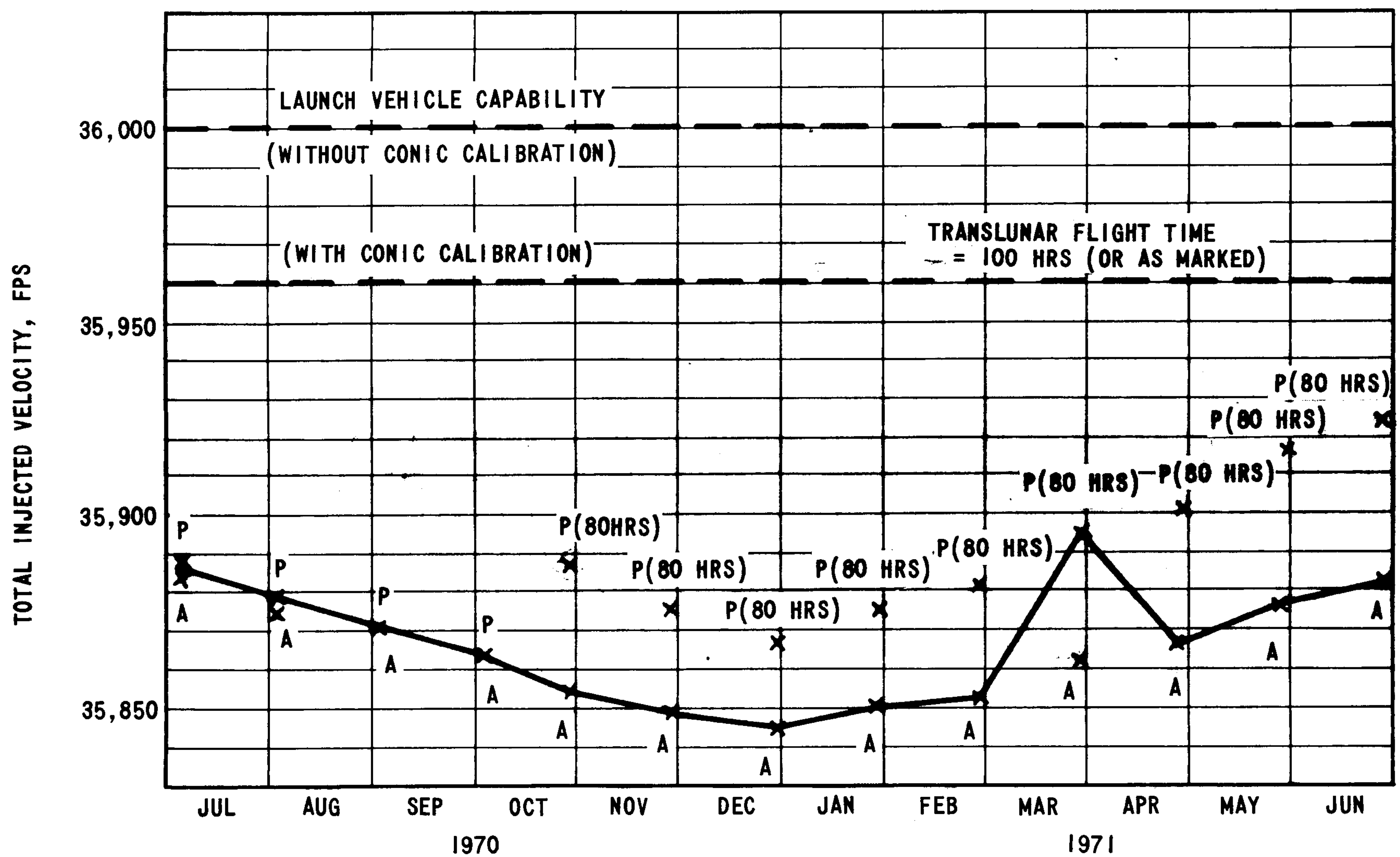

FIGURE 8 - TLI TOTAL VELOCITY FOR MISSIONS TO LITTROW RILLE
(NON-FREE RETURN CONIC TRAJECTORIES)

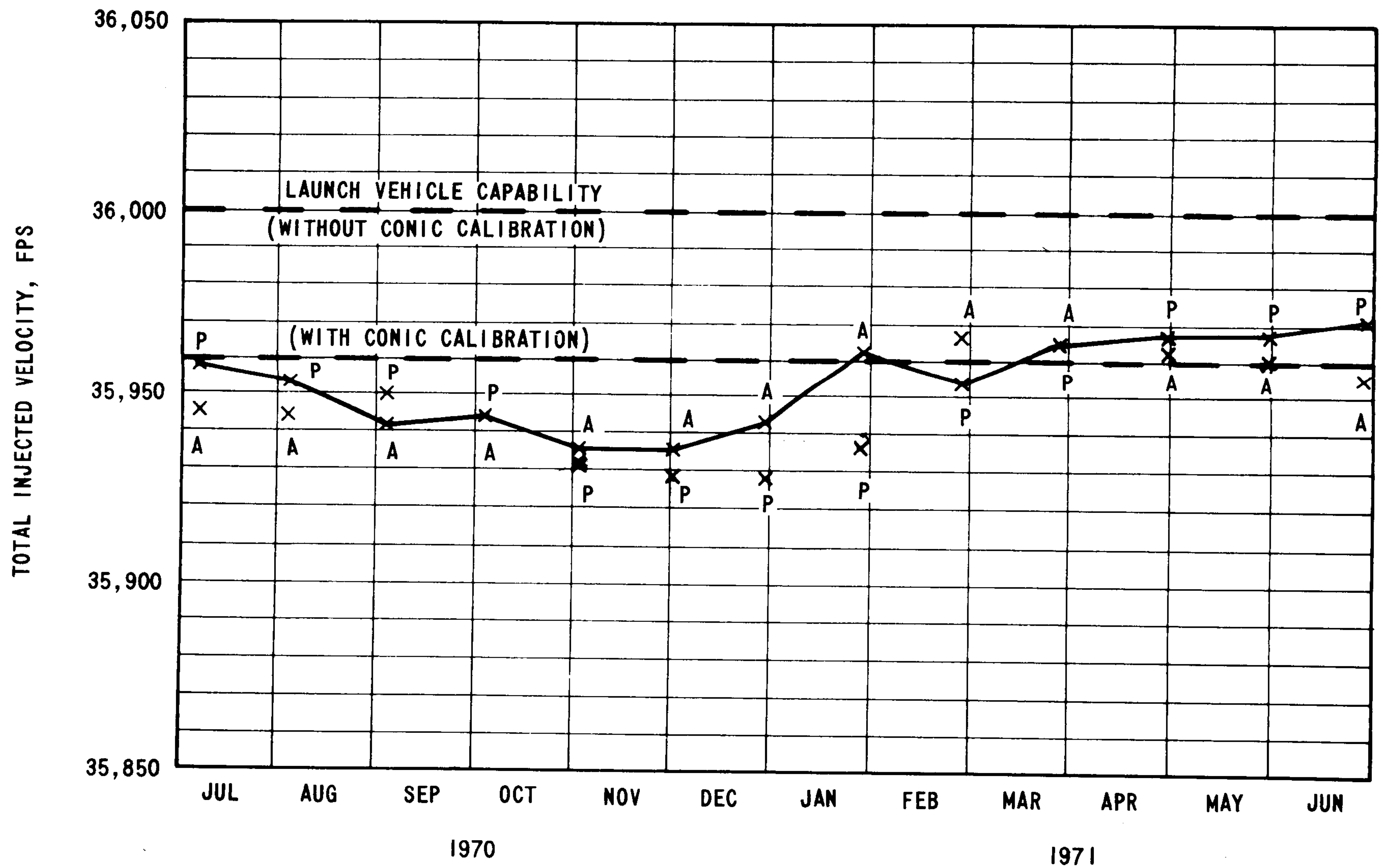

FIGURE 9 - TLI TOTAL VELOCITY FOR MISSIONS TO CENSORINUS
(FREE RETURN CONIC TRAJECTORIES)

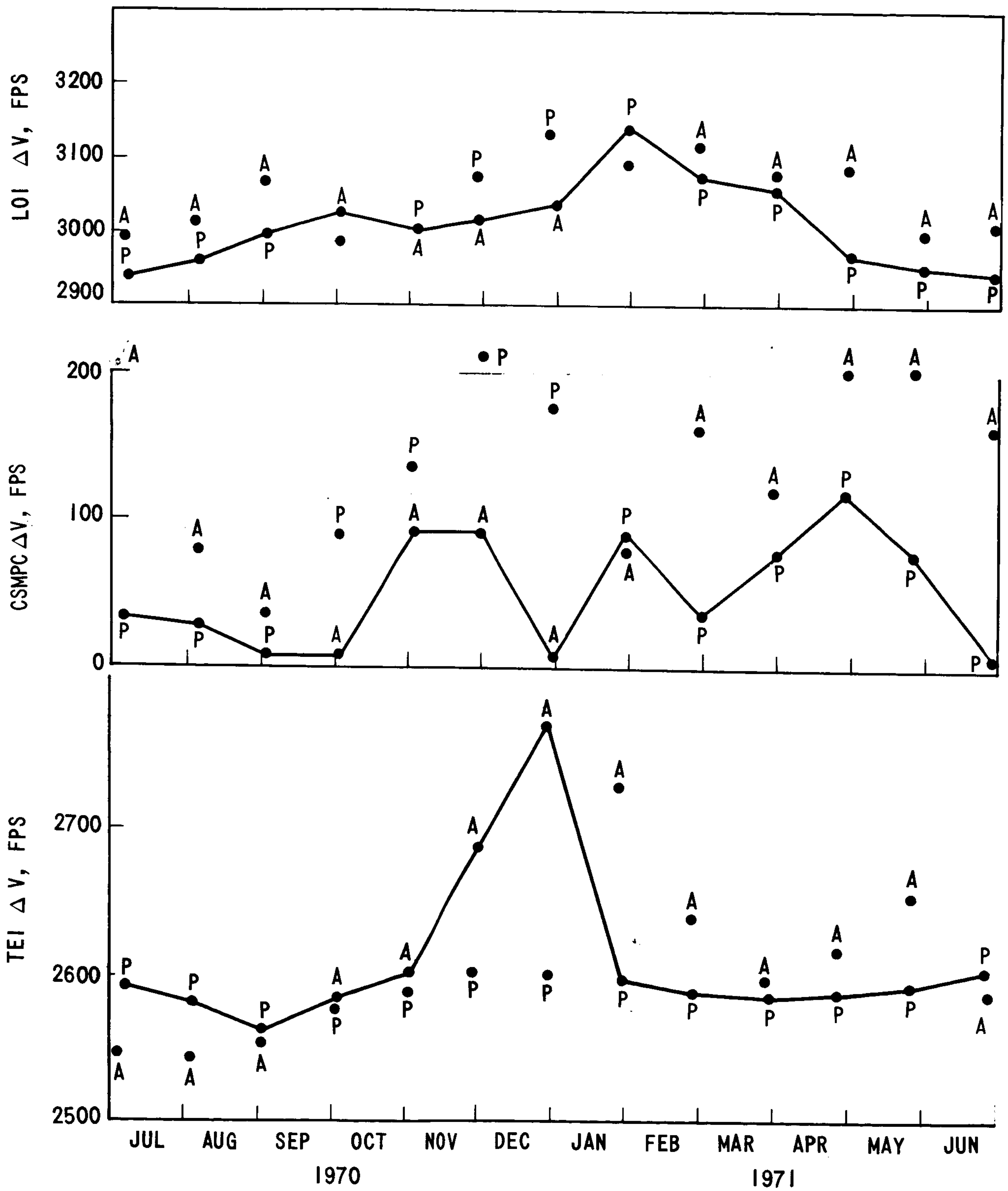

FIGURE 10 - ΔV COST FOR MISSIONS TO II-P-2
(FREE RETURN CONIC TRAJECTORIES)

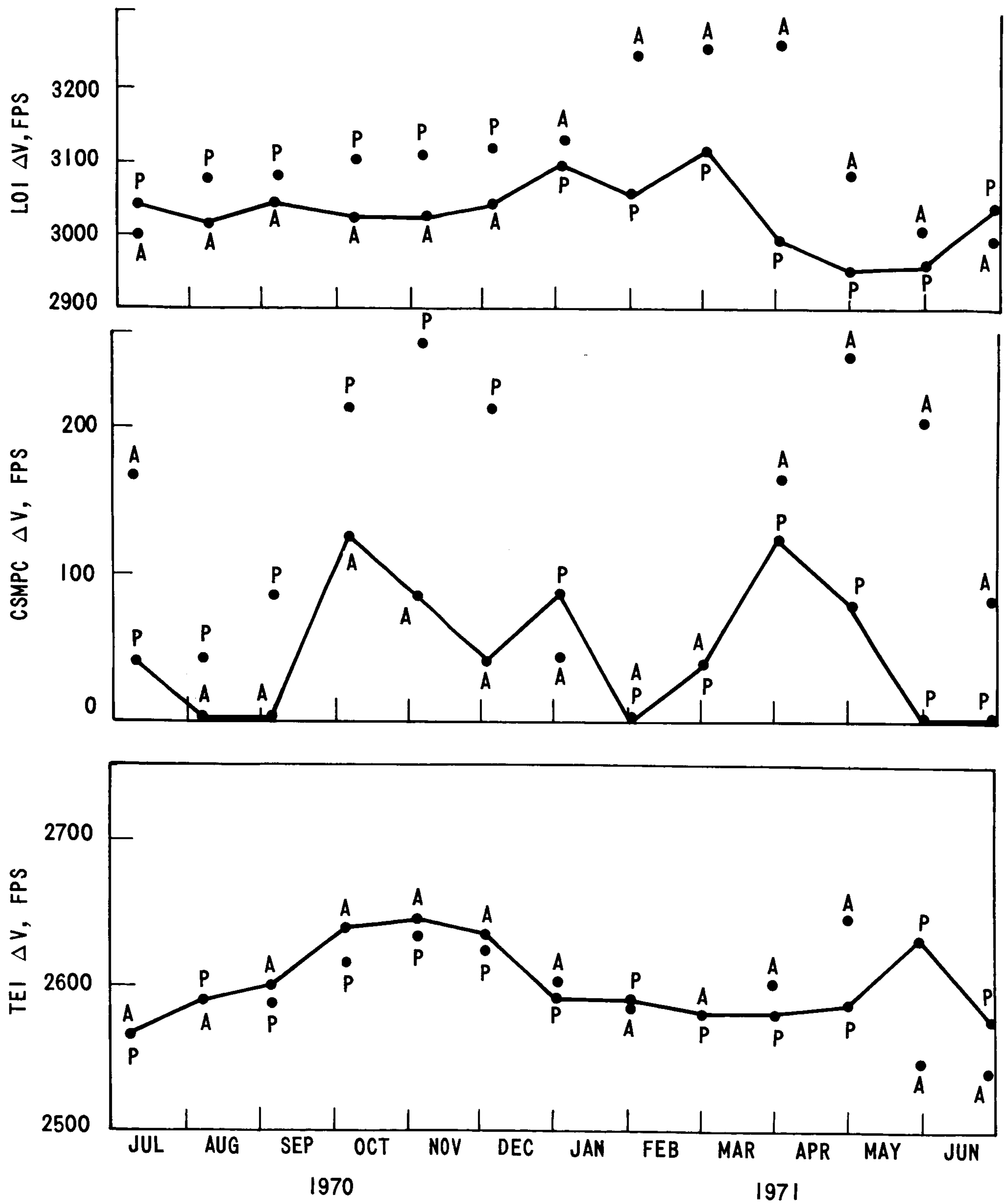

FIGURE 11 - ΔV COST FOR MISSIONS TO II-P-8
(FREE RETURN CONIC TRAJECTORIES)

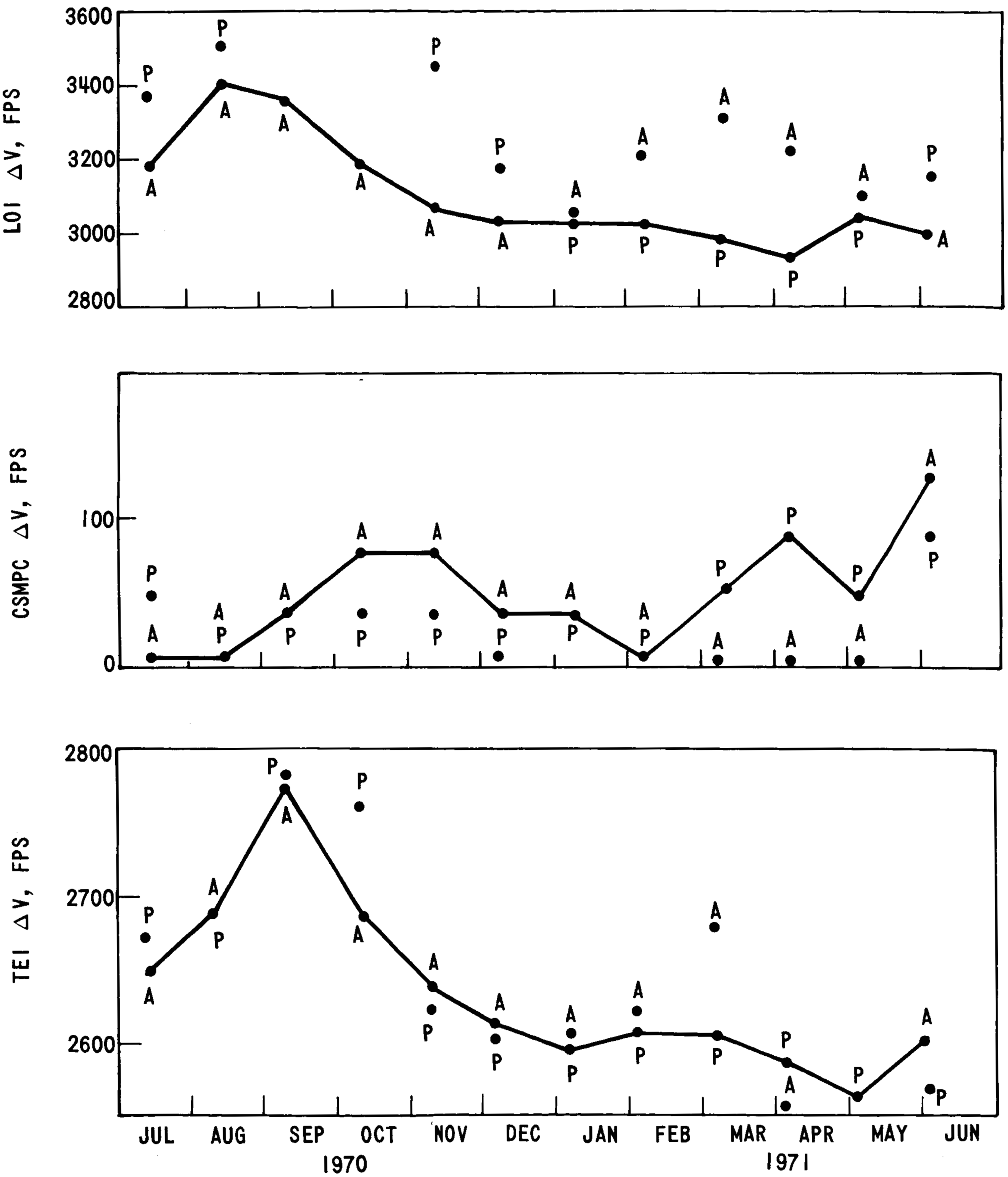

FIGURE 12 - ΔV COST FOR MISSIONS TO III-P-12
(FREE RETURN CONIC TRAJECTORIES)

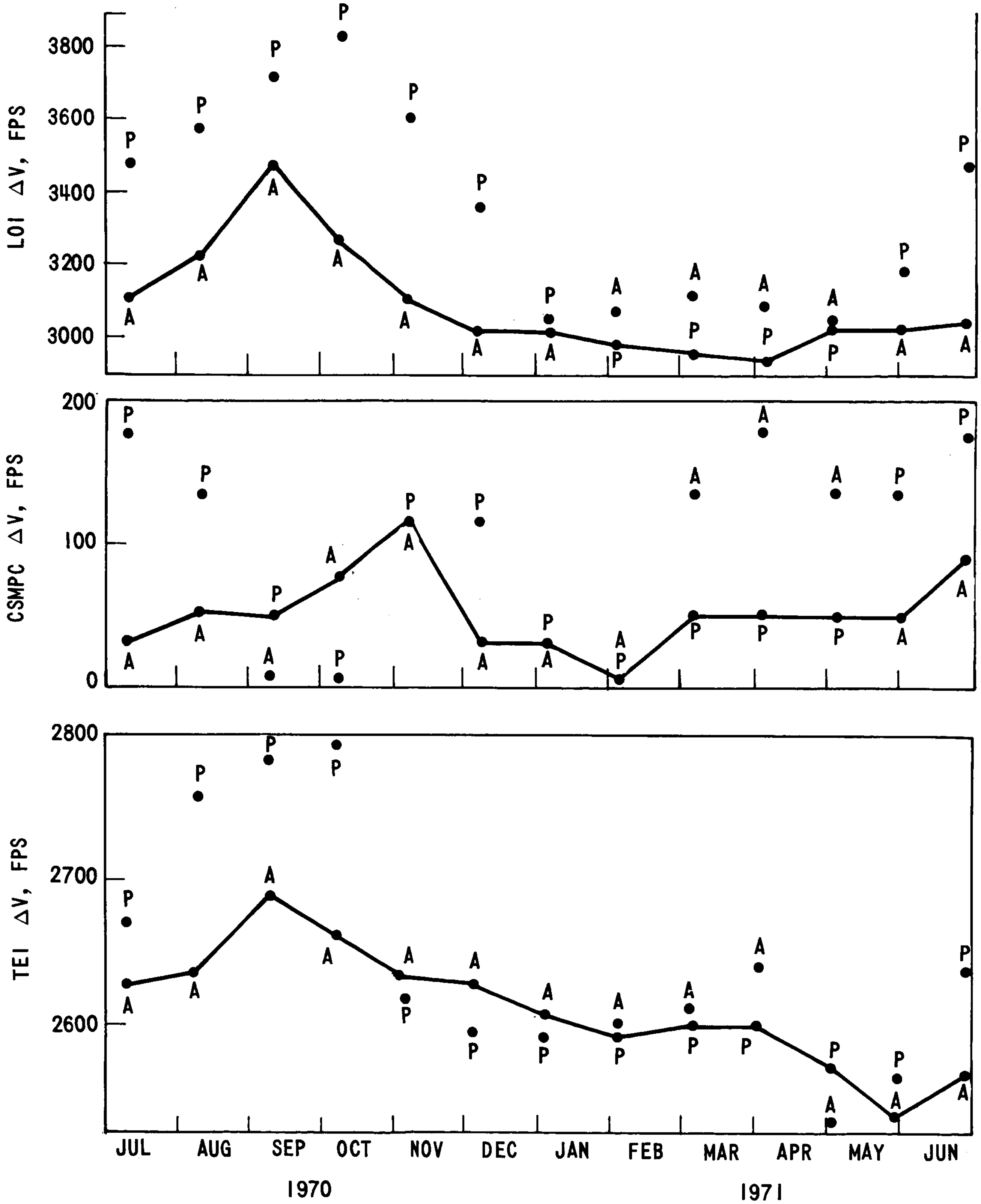

FIGURE 13 - ΔV COST FOR MISSIONS TO FRA MAURO
(FREE RETURN CONIC TRAJECTORIES)

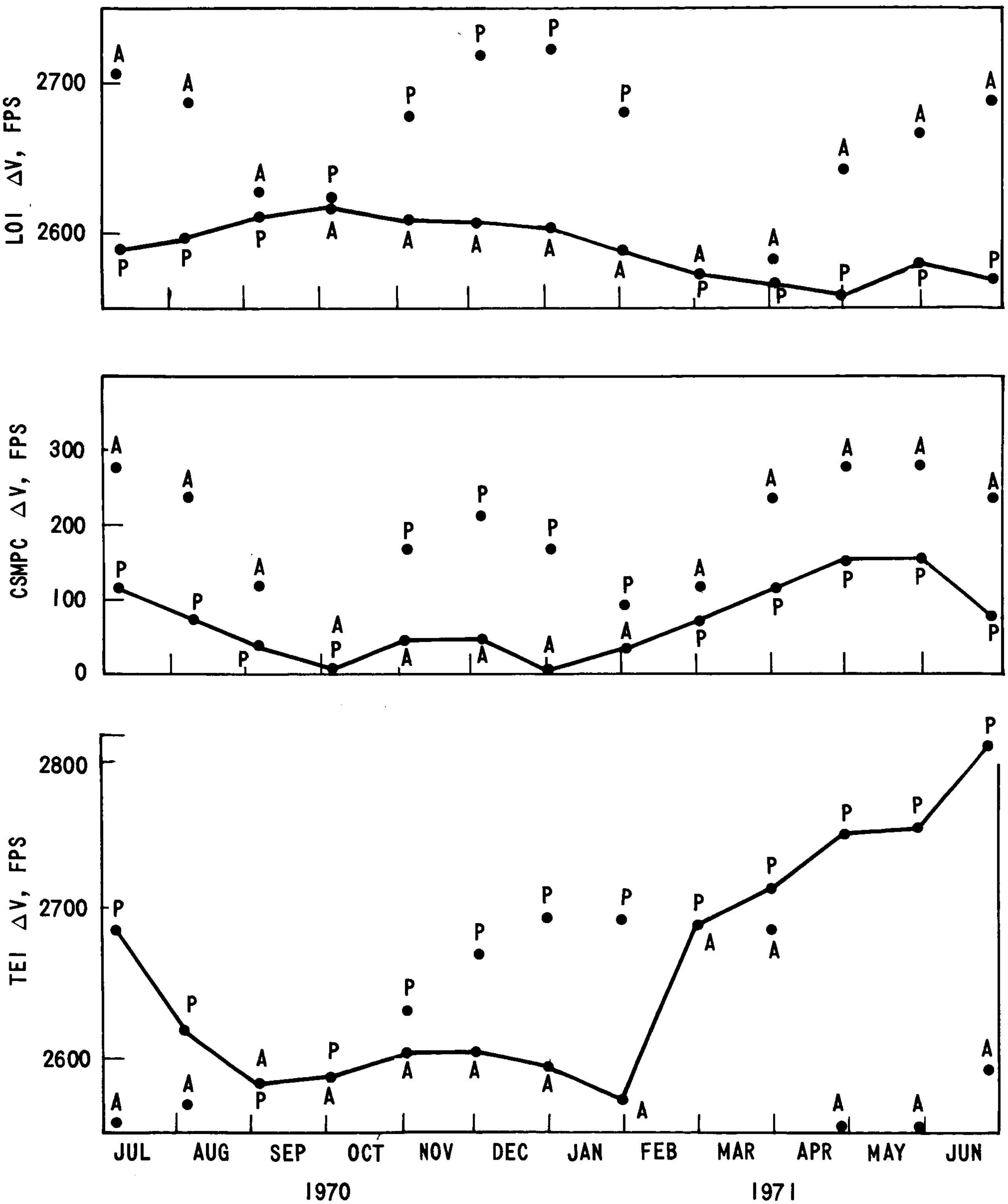

FIGURE 14 - ΔV COST FOR MISSIONS TO ABULFEDA
(NON-FREE RETURN CONIC TRAJECTORIES)

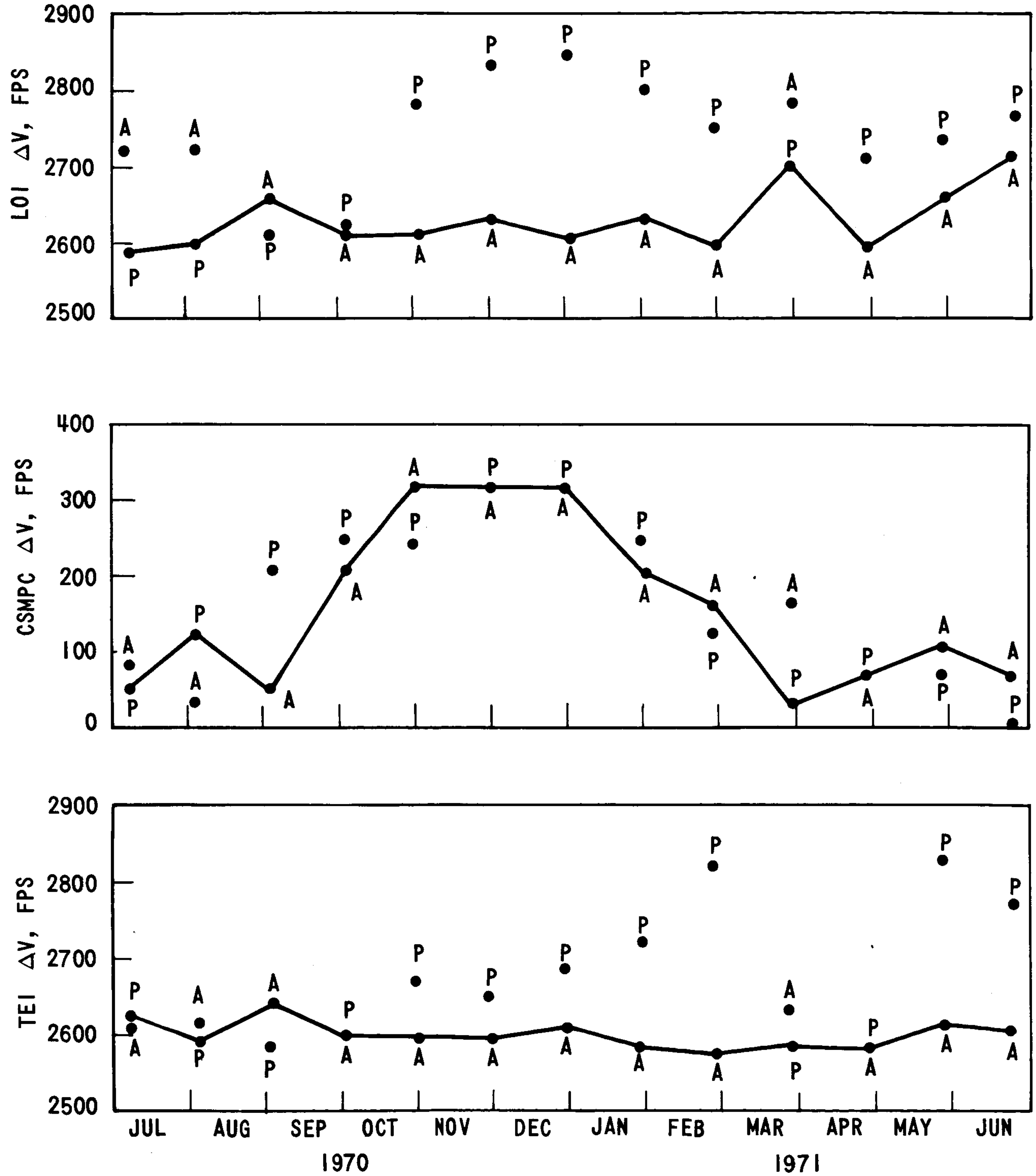

FIGURE 15 - ΔV COST FOR MISSIONS TO LITTROW RILLE
(NON-FREE RETURN CONIC TRAJECTORIES)

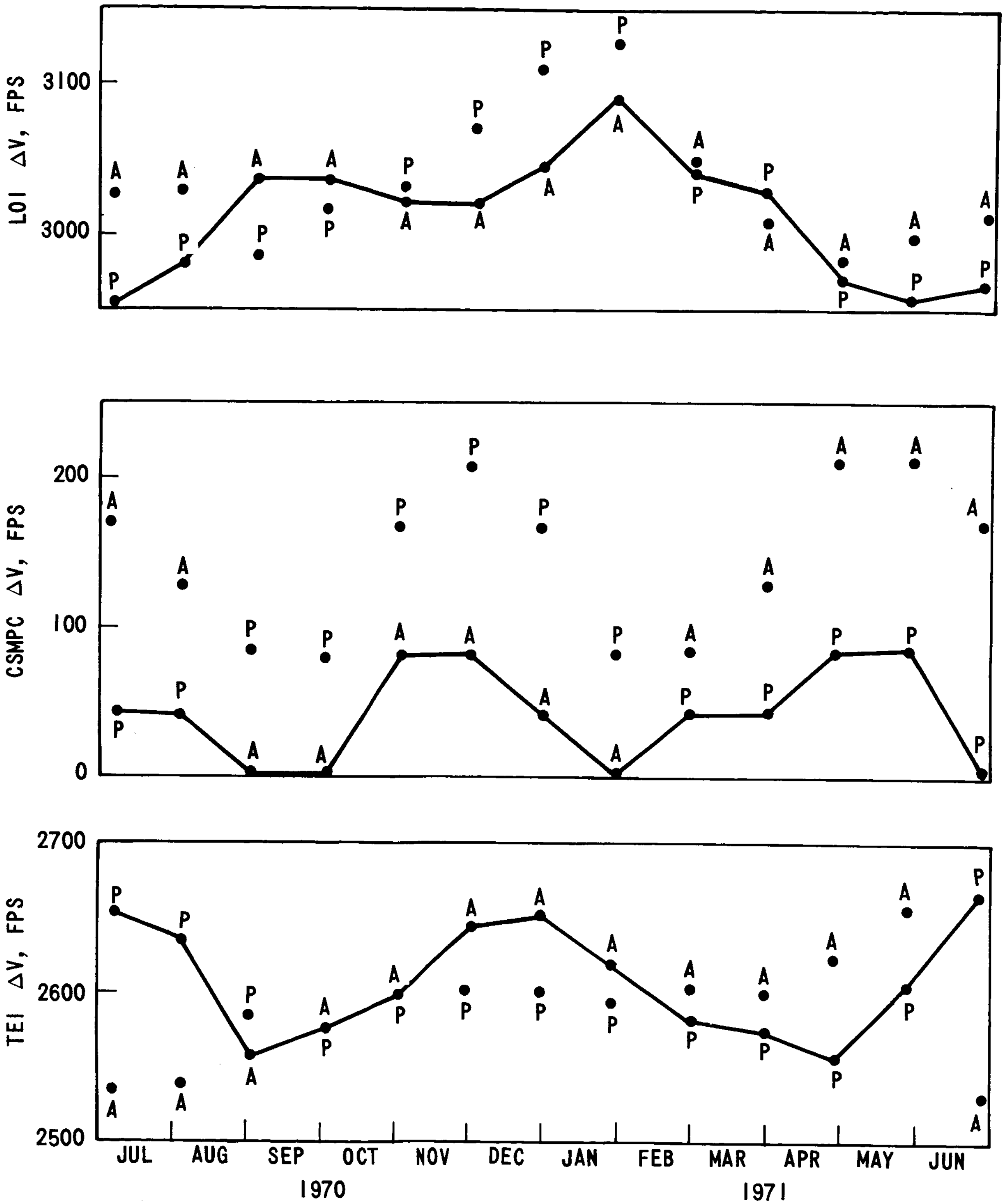

FIGURE 16 - ΔV COST FOR MISSIONS TO CENSORINUS
(FREE RETURN CONIC TRAJECTORIES)

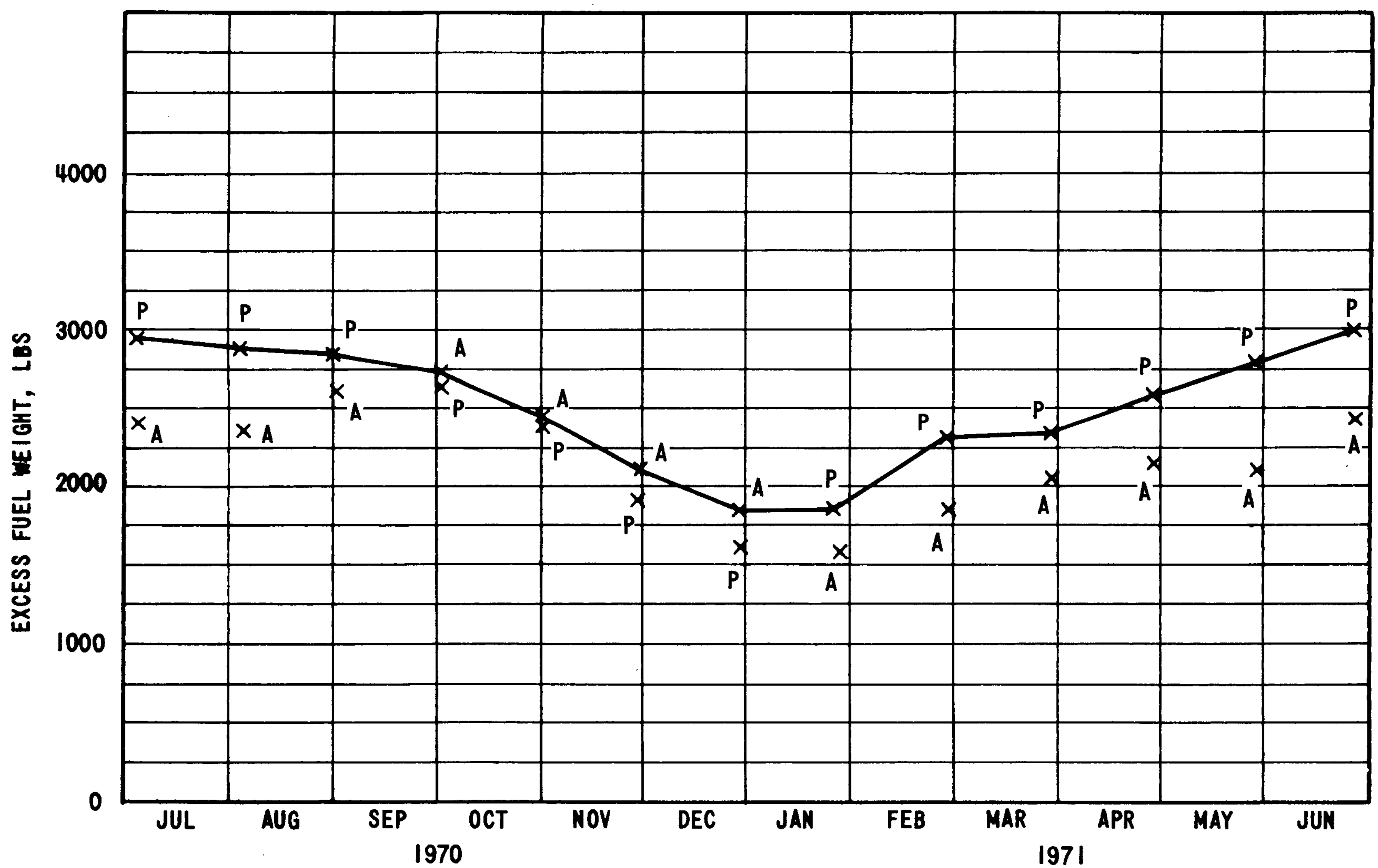

FIGURE 17 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO II-P-2
(FREE RETURN CONIC TRAJECTORIES)

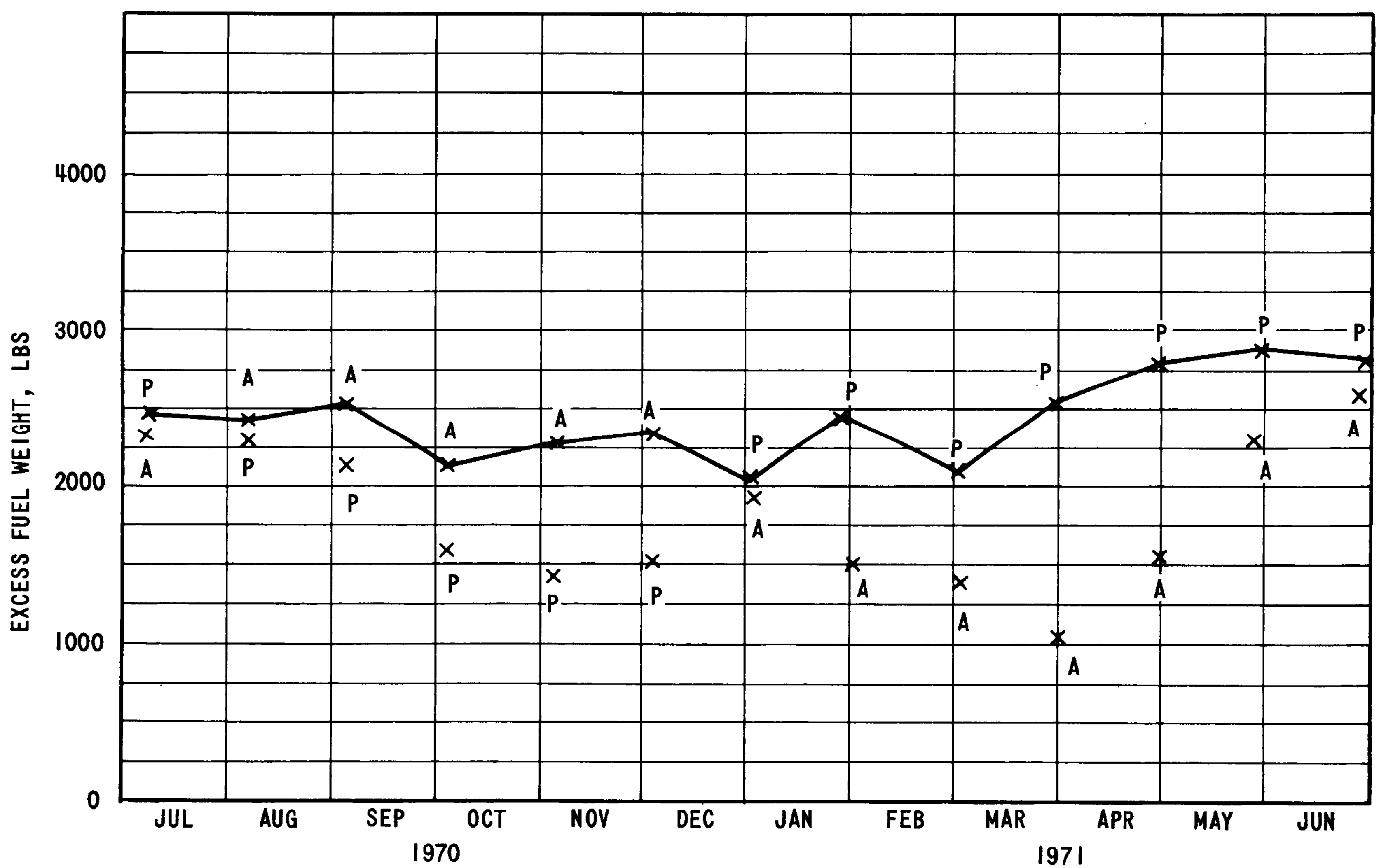

FIGURE 18 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO 11-P-8
(FREE RETURN CONIC TRAJECTORIES)

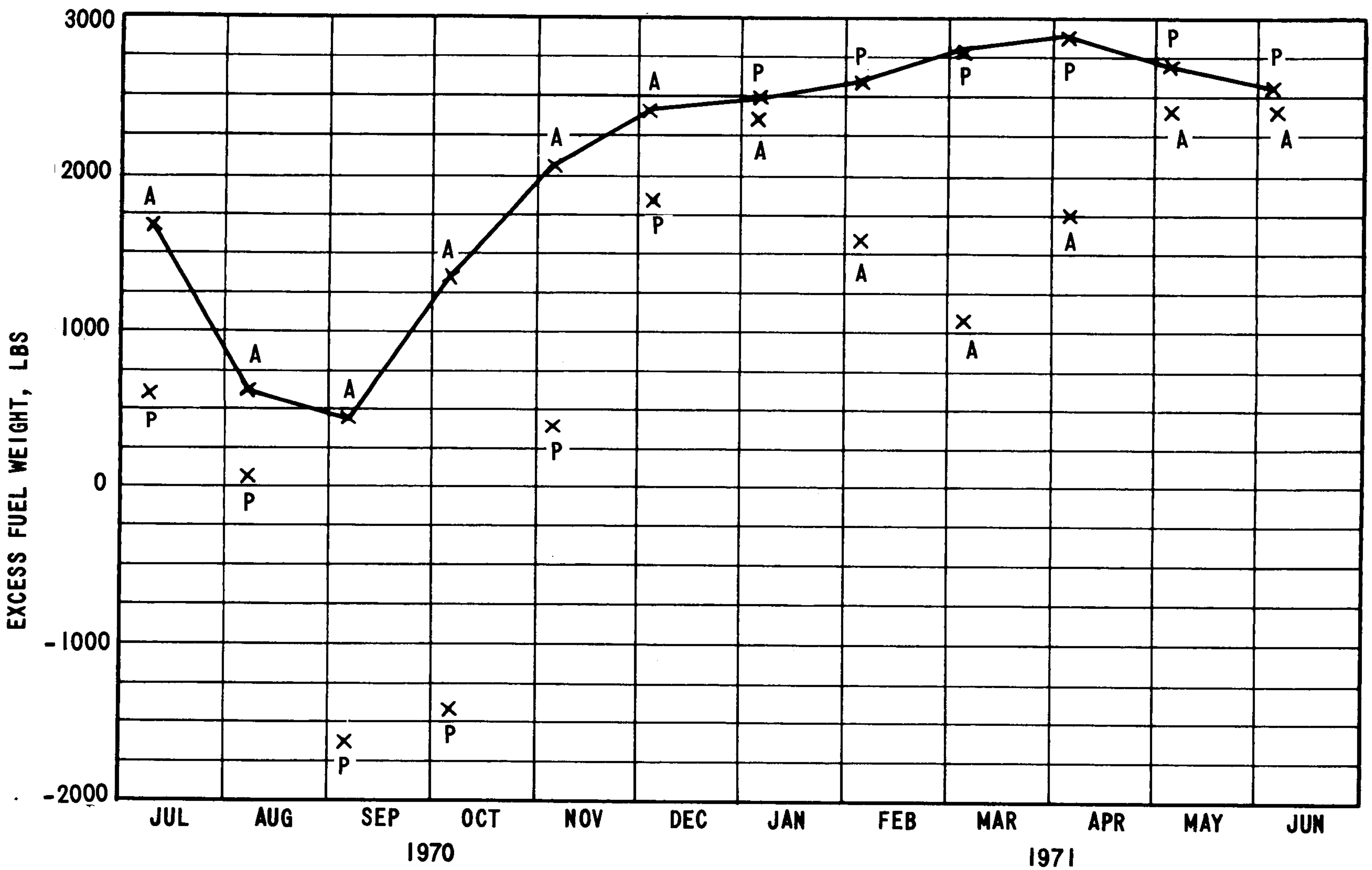

FIGURE 19 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO III-P-12
(FREE RETURN CONIC TRAJECTORIES)

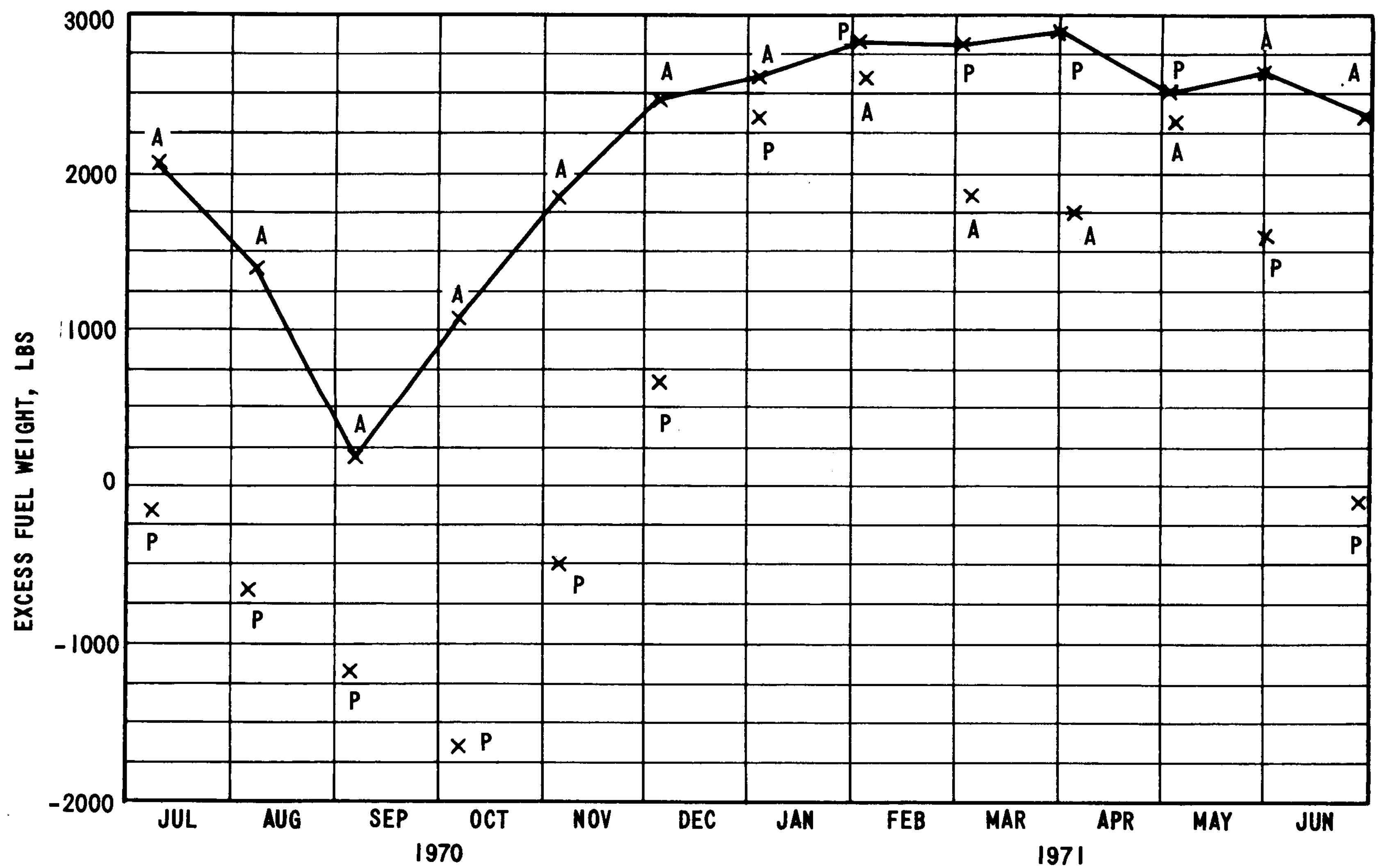

FIGURE 20 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO FRA MAURO
(FREE RETURN CONIC TRAJECTORIES)

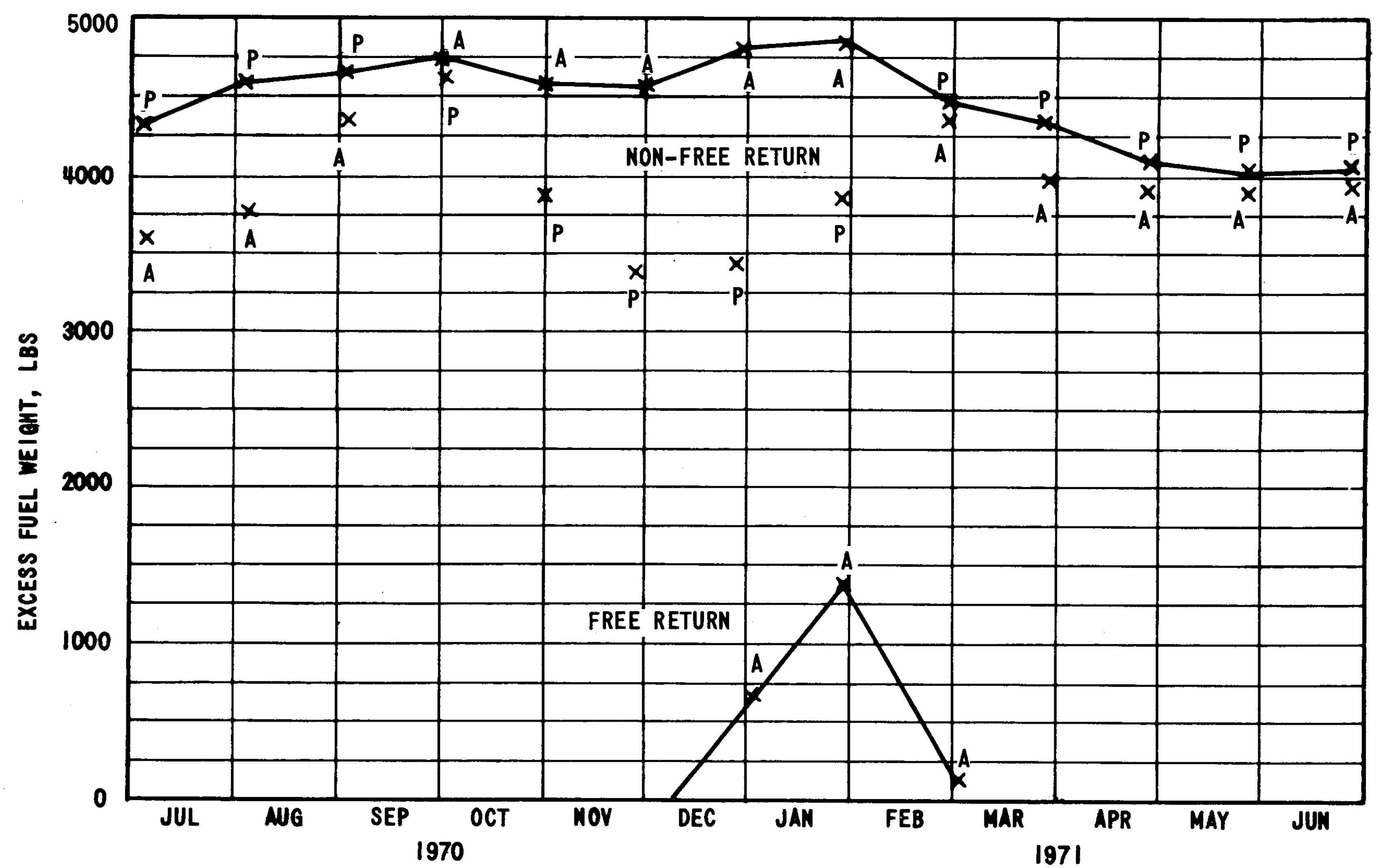

FIGURE 21 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO ABULFEDA
(FREE AND NON-FREE RETURN CONIC TRAJECTORIES)

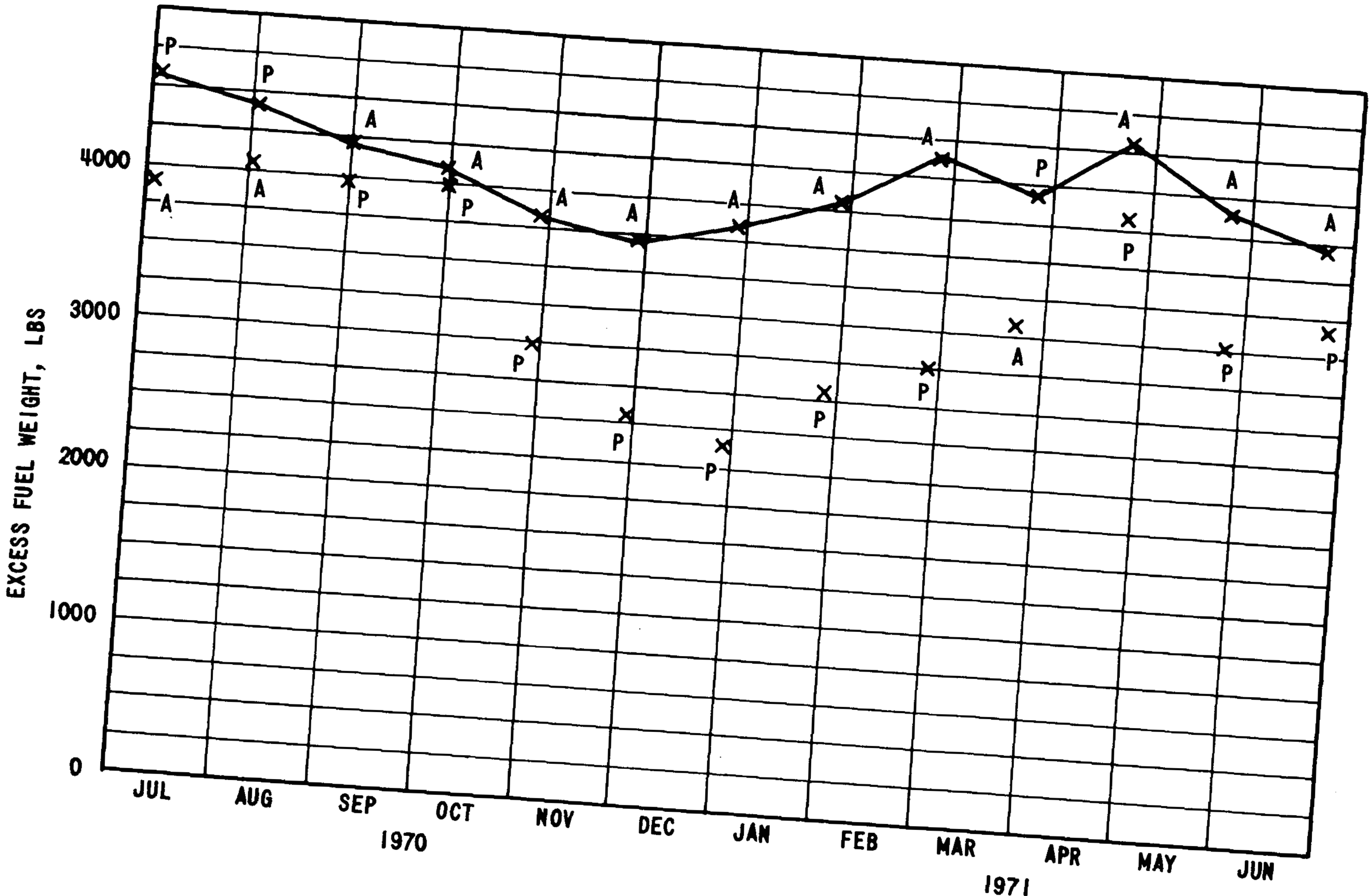

FIGURE 22 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO LITTROW RILLE (NON-FREE RETURN CONIC TRAJECTORIES)

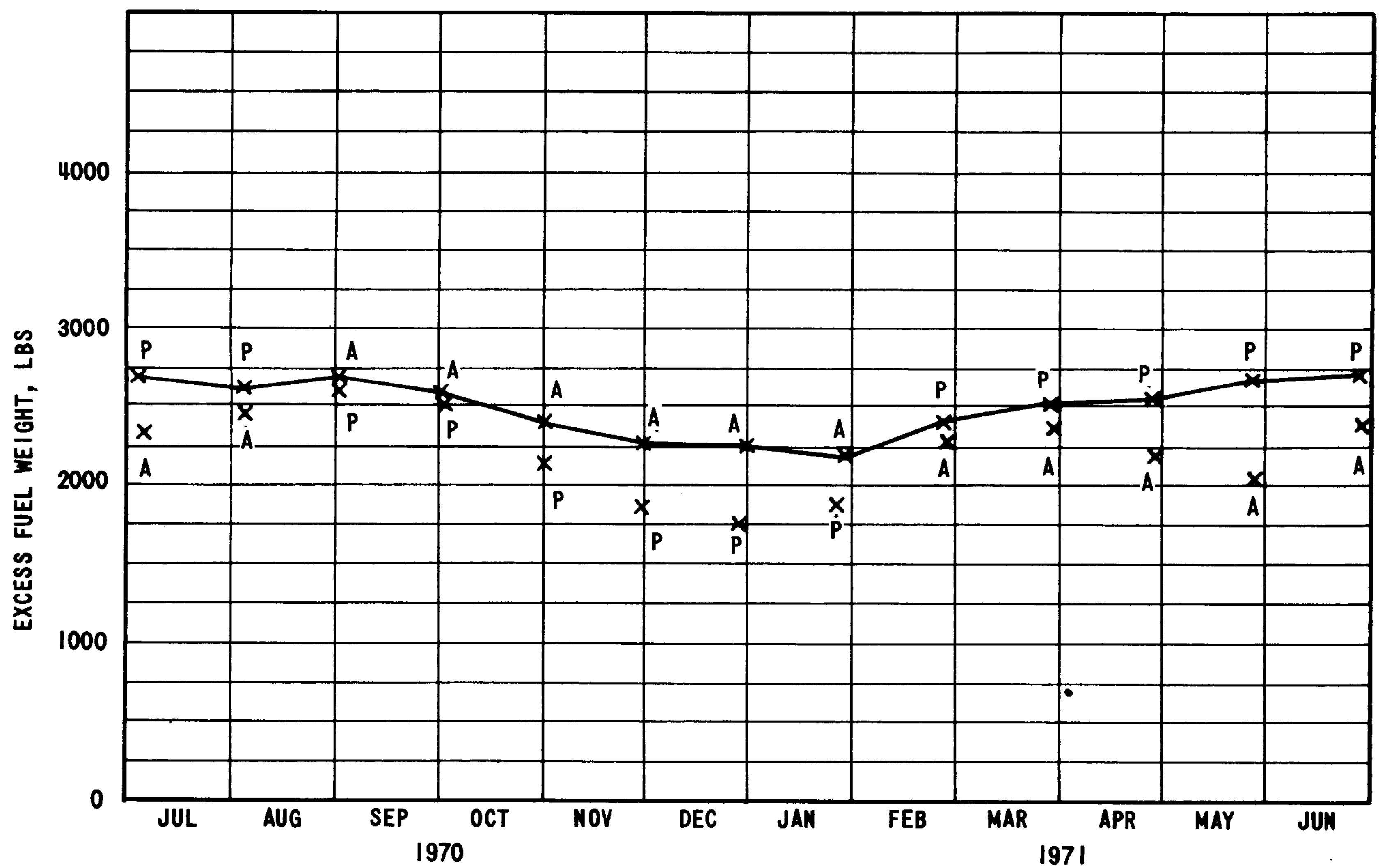

FIGURE 23 - EXCESS SPS FUEL WEIGHT FOR MISSIONS TO CENSORINUS
(FREE RETURN CONIC TRAJECTORIES)

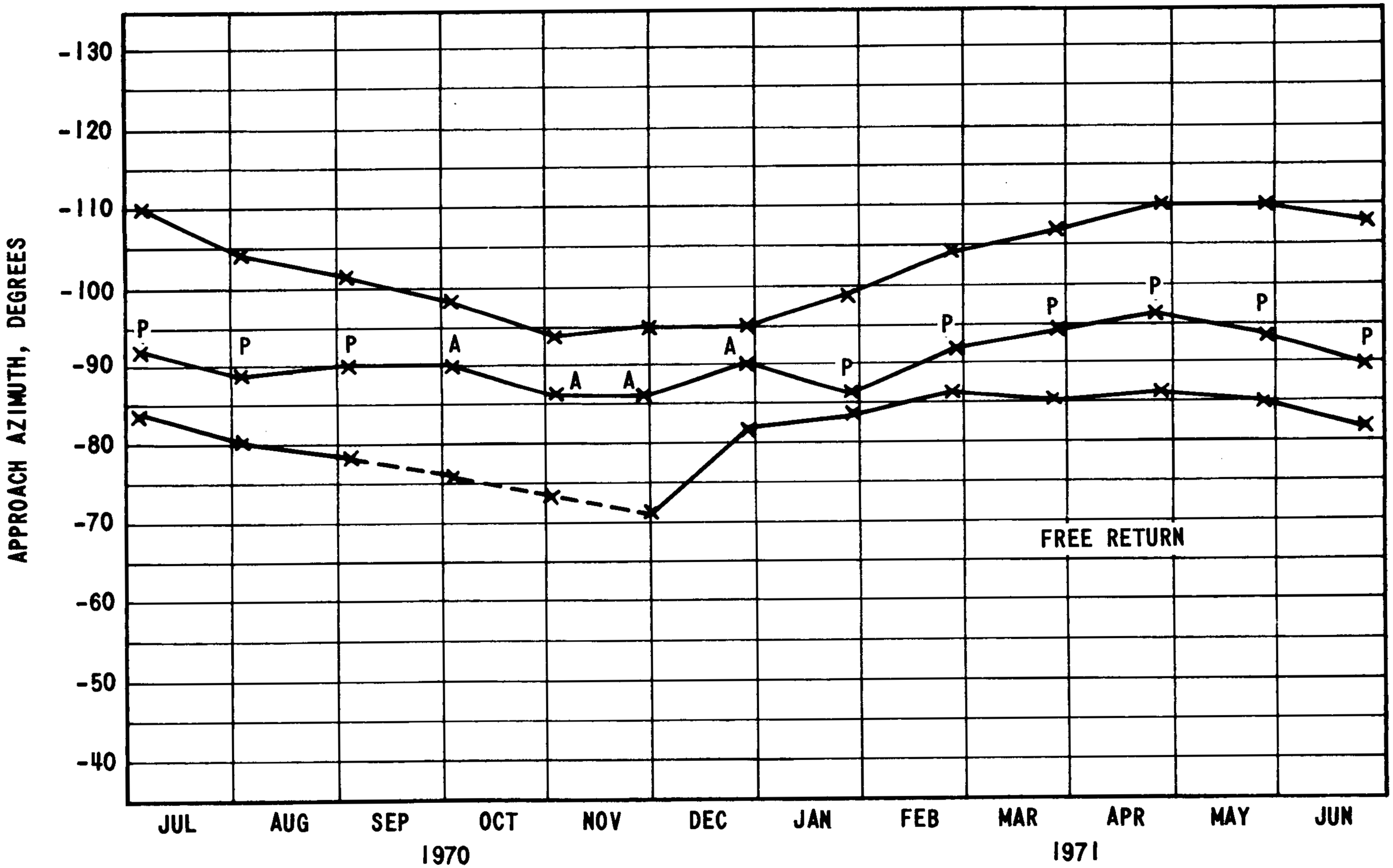

FIGURE 24 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO II-P-2

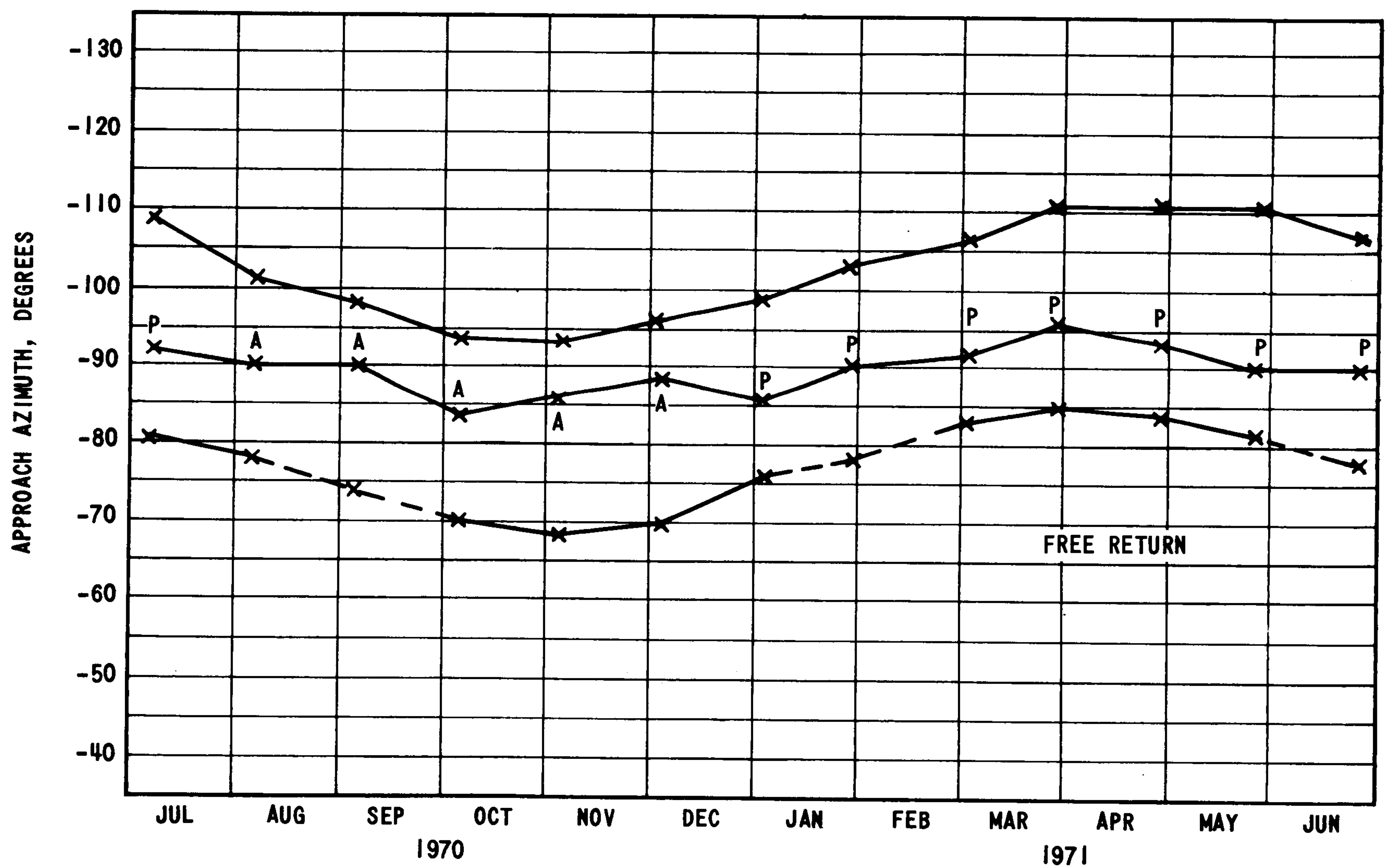

FIGURE 25 - OPTIMUM APPROACH AZIMUTH AND RANGE TO APPROACH AZIMUTH FOR MISSIONS TO 11-P-8

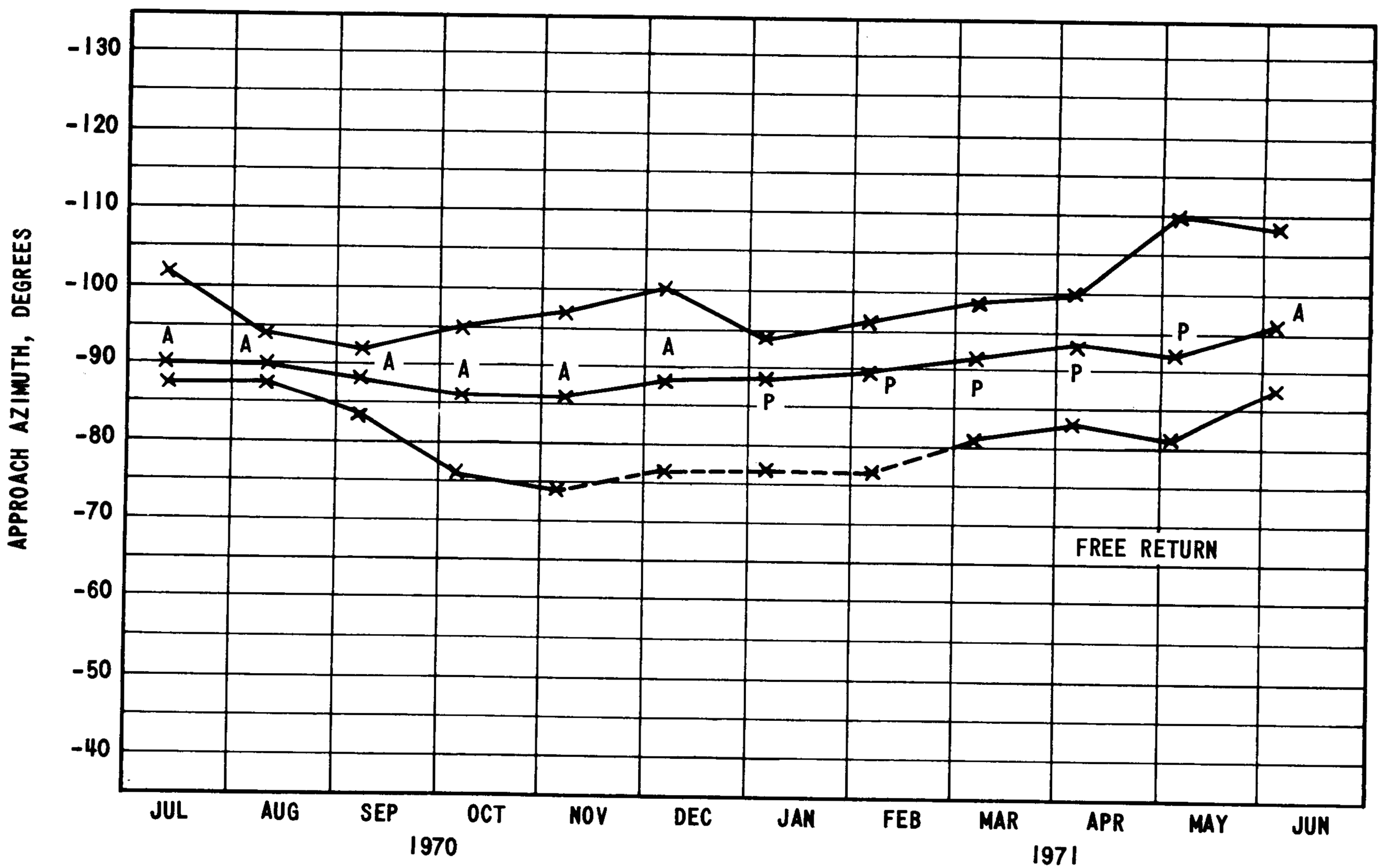

FIGURE 26 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO III-P-12

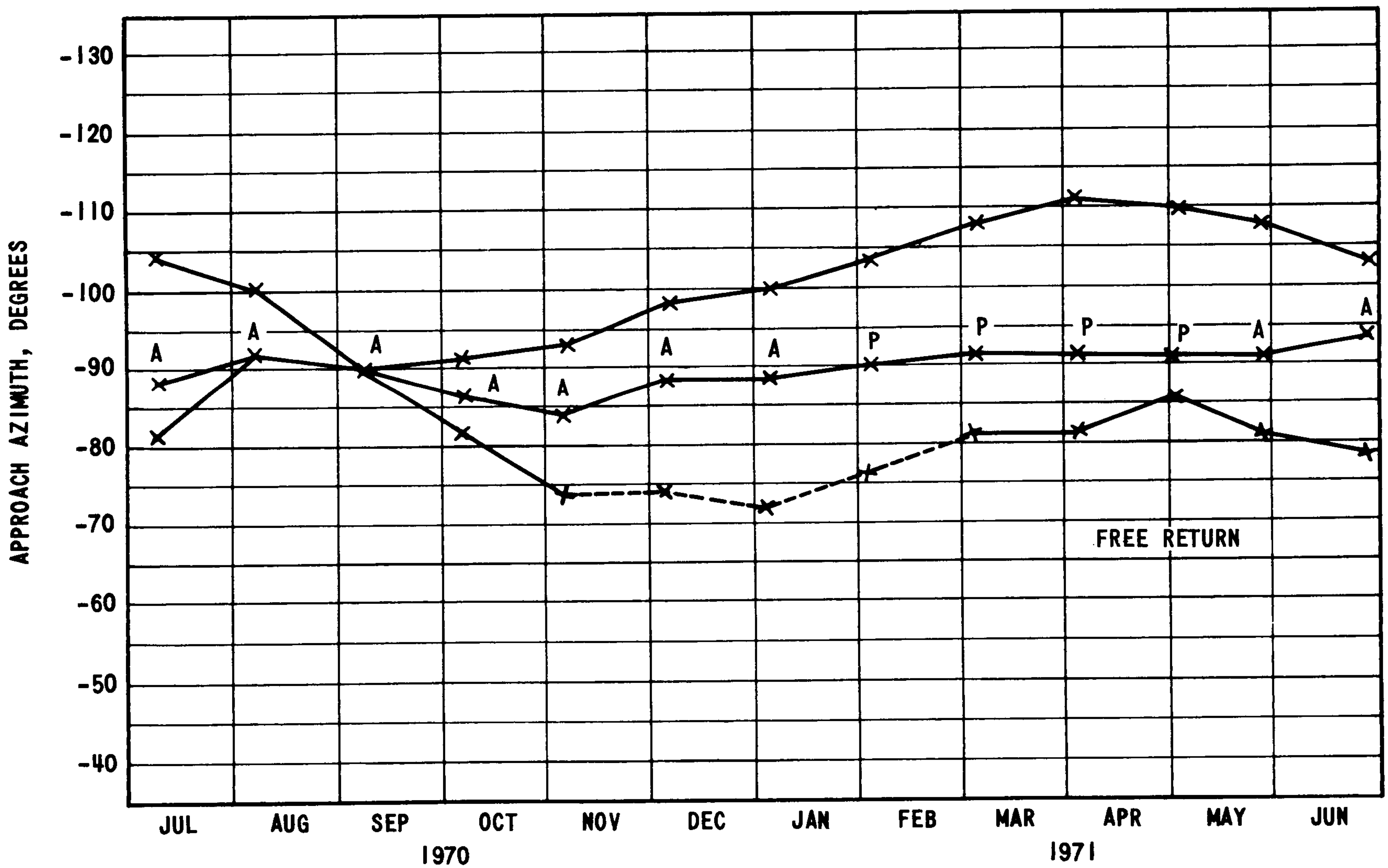

FIGURE 27 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO FRA MAURO

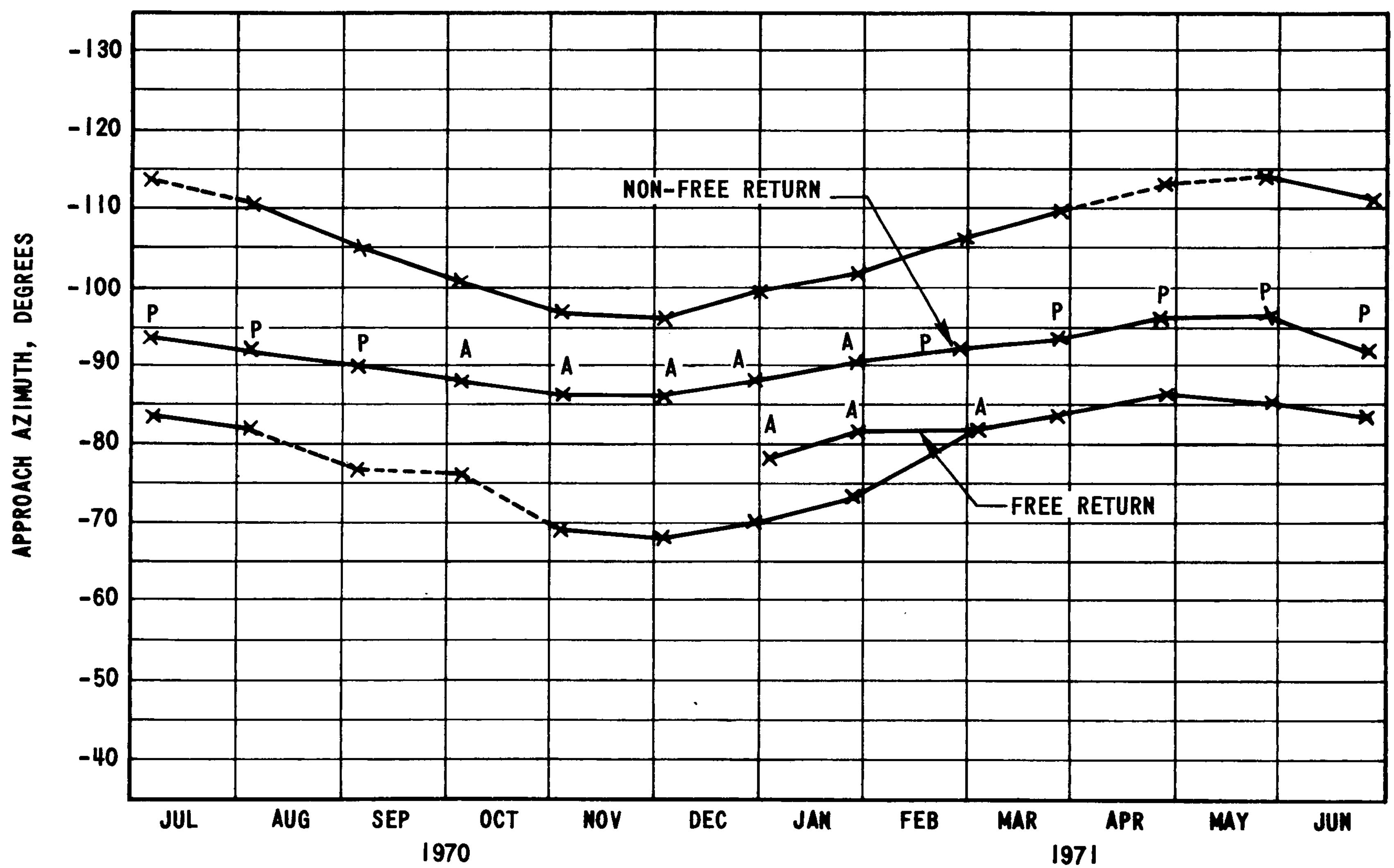

FIGURE 28 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO ABULFEDA

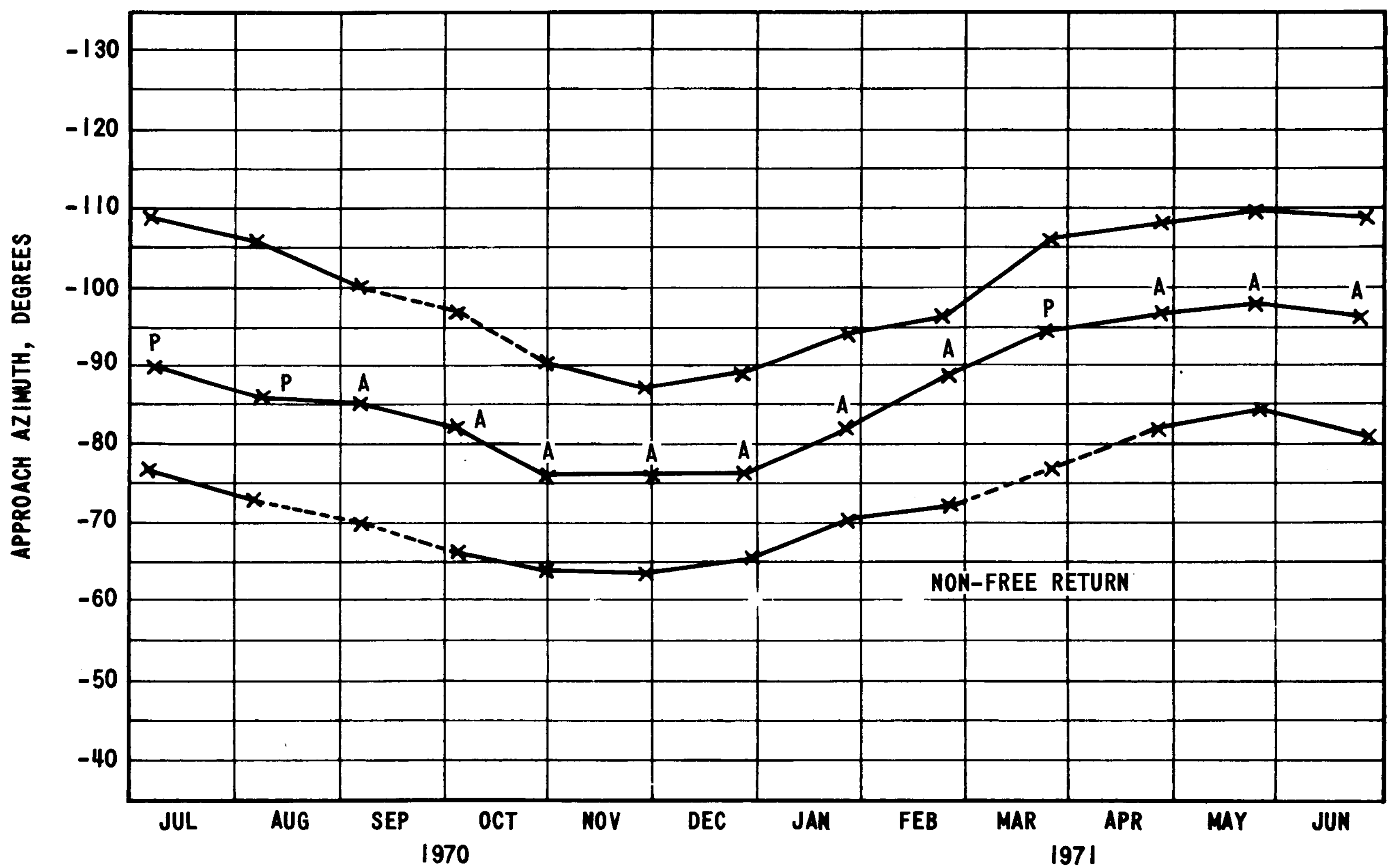

FIGURE 29 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO LITTROW RILLE

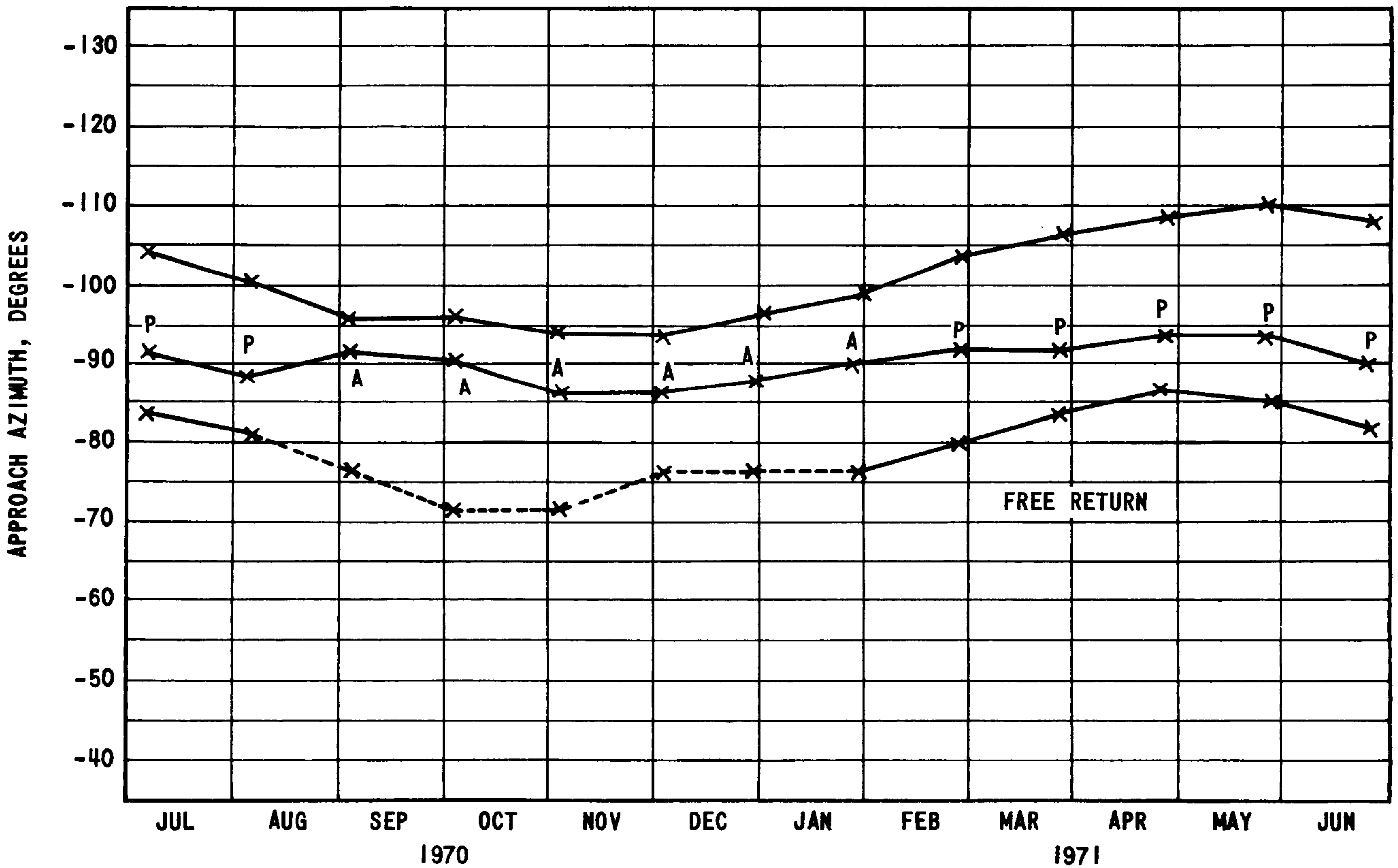

FIGURE 30 - OPTIMUM APPROACH AZIMUTH AND RANGE OF APPROACH AZIMUTH FOR MISSIONS TO CENSORINUS